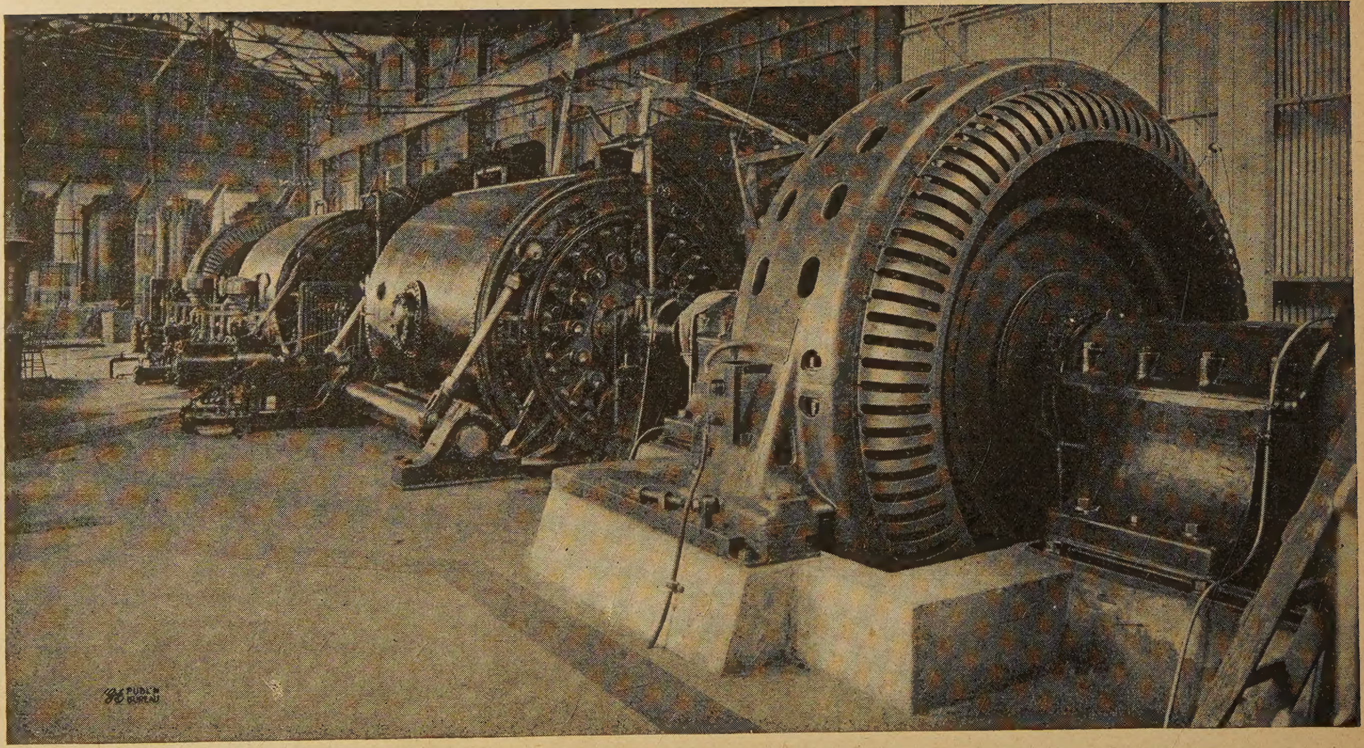

TWO 5000-K.W. 4000-VOLT GENERATORS, SHOSHONE POWER HOUSE, CENTRAL COLORADO POWER COMPANY

Courtesy of General Electric Company

Cyclopedia

of

Applied Electricity

A General Reference Work on

DIRECT-CURRENT GENERATORS AND MOTORS, ALTERNATING-CURRENT MACHINERY, ARMATURE WINDING, STORAGE BATTERIES, INTERIOR ELECTRIC WIRING, ELECTRIC LIGHTING, METERS, INDUSTRIAL CONTROLLERS, ELECTRIC RAILWAYS, RAILWAY SIGNALING AND CAR LIGHTING, POWER STATIONS, SWITCHBOARDS, TRANSMISSION AND DISTRIBUTION SYSTEMS, ELECTROCHEMISTRY, WELDING, ETC.

Prepared by a Corps of

ELECTRICAL EXPERTS, ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

EIGHT VOLUMES

AMERICAN TECHNICAL SOCIETY
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Grateful acknowledgment is here made also for the valuable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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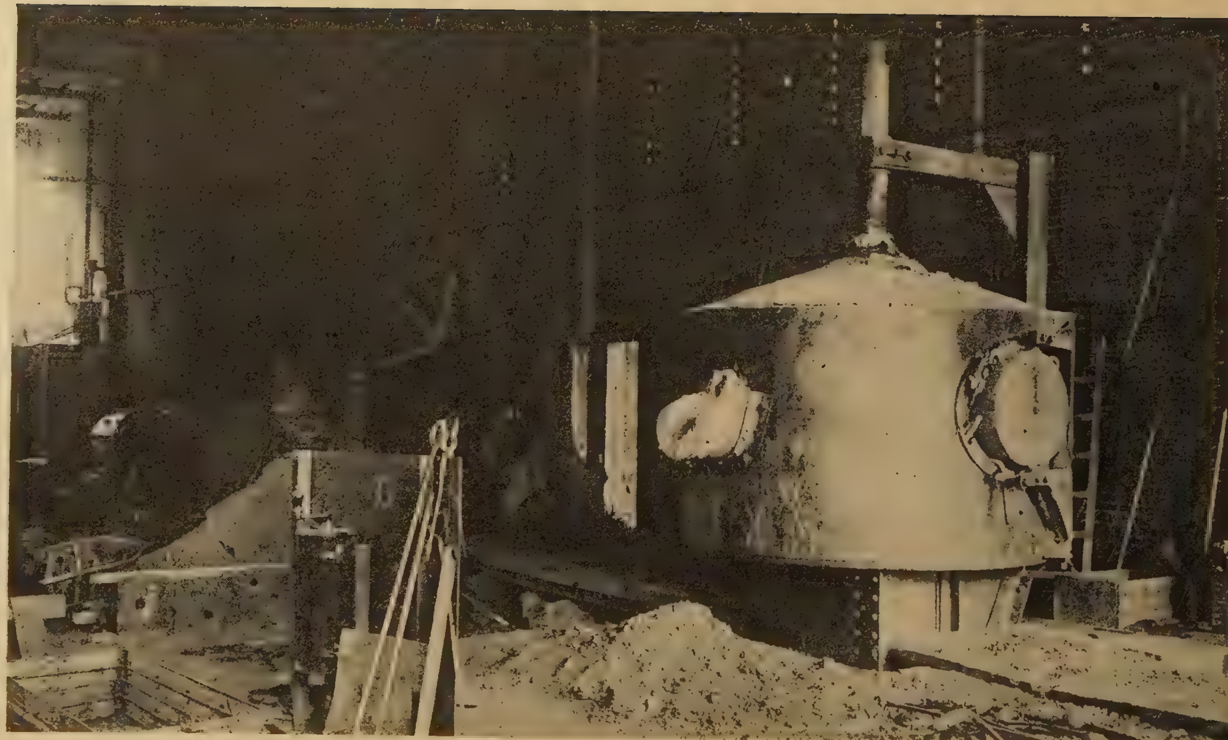

MODIFIED GIROD ELECTRIC FURNACE INSTALLED FOR CHICAGO ELECTRIC CASTINGS COMPANY

Courtesy of the Iron Age

Foreword

ELECTRICITY, during the last hundred years, has advanced from an interesting yet mysterious phenomenon to the leading source of energy on the globe. Thousands of master minds have studied experimental data and have verified theories, while more practical heads have utilized the principles discovered. The applications of the electric current are numberless and are to be found in every home, even unto the highways and byways of our less thickly populated districts. The visible results are on every side. Think of the important parts the generator and motor play in our industrial life; call to mind the immense power plants which are to be found all over the country; stop and realize the convenience of the electric light when we turn it on in our home, or the electric car when we take it at a near-by corner. Think again of the telephone, the wire and wireless telegraphs, and the thousands of other applications of the electric spark and electric energy which contribute to our daily comfort.

¶ With the increase in complexity of the machines and devices and the larger part which the science of electricity played in the life and activities of the nation came the increasing necessity for an authoritative work of reference. It was to satisfy this acknowledged need that the Cyclopedia of Applied Electricity was created in 1905, and for more than a decade it has held an enviable place in the field of electrical literature. By repeated revisions the publishers have kept the material up to date, and the present Cyclopedia, with its extensive revision and enlargement, is a worthy successor to previous editions. Being a complete and practical working treatise on the generation and application of electrical energy, one finds in the Cyclopedia logical discussions of direct and alternating currents with instructive sections on such subjects as Armature Winding, Storage Batteries and Transformers. Methods of Distribution and Transmission are given adequate treatment, while the article on Interior Electric Wiring takes up the

practical methods and equipment used in preparing buildings for the use of electric light or power. Commercial uses, such as Lighting, Welding, Transportation and Communication, are exhaustively treated. The discussion includes the construction as well as the management of devices, instruments, and machines in practical use, while the treatment of operating troubles is complete.

¶ Owing to the use of many special words and terms, a glossary has been included in Volume VIII. The definitions are given in simple language, and where possible reference is made to the volume and page where added information may be found.

¶ Throughout, the Cyclopedia is as scientifically correct as any work could be, and yet the treatment of the various subjects is as free as possible from abstruse mathematics and unnecessary technical phrasing, particular attention being given to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are given whenever they may be helpful in explaining the subject, while the numerous illustrations and blue-printed inserts furnish complete pictorial aid to the text.

¶ Books on electrical topics would, if all gathered in a common library, contain so many duplicate pages as to entail a great waste of time upon one trying to keep up with electrical progress. To overcome this difficulty the publishers of this Cyclopedia have gone to original sources, and have secured, as writers of the various sections, men of wide practical experience and thorough technical training. Each writer is an acknowledged authority on the subject which he covers. The contributions of these men have been correlated by our Board of Editors into the logical and unified Cyclopedia here presented.

¶ In conclusion, acknowledgment is due to the staff of Authors and Collaborators, whose hearty co-operation has made this work possible.

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VOLUME VI

*For page numbers, see foot of pages.

†For professional standing of authors, see list of Authors and Collaborators at front of volume.

FLOOD-LIGHTED TOWER OF WOOLWORTH BUILDING, NEW YORK

ELECTRIC LIGHTING

PART I

UNITS OF MEASUREMENT

The Candle. A generation or two ago when new light sources began to supersede the candle, it was most natural that the illuminating power of these new sources should be expressed in terms of the candle, familiar to all. It is probable that the very first comparisons of two light sources were made by setting up the two lamps in the line of vision and gaging them by means of the eye, the most natural direction in which to look at the sources being the horizontal. A glance at Fig. 1 shows that the eye (an extremely fallible instrument of light measurement at its

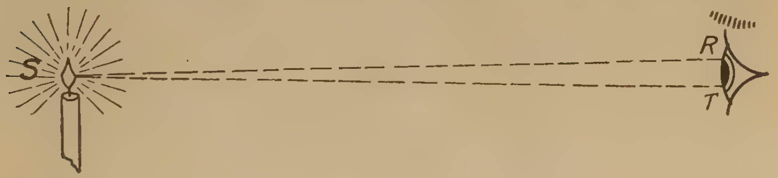

Fig. 1. Only Slender Cone of Light Reaches Eye

best) is capable of measuring only a very slender cone of light at one time; in fact, if the eye is an appreciable distance from the source, the cone RST becomes virtually a single line. While there is an infinite number of directions from which the eye might look at the source, the light-giving power in a horizontal direction was made the basis of comparisons. As newer illuminants appeared they were rated according to their strength in this same direction and were stated to give so many candles, so that when we say a lamp gives 10 candles, we really mean that its intensity or strength in a horizontal direction is equal to that of a group of ten standard candles. This rating of a lamp is made by means of an instrument known as a photometer, a description of which will follow later. One essential point to remember in this connection is that the candle-power of a lamp represents the

intensity in one direction only. In practice, it has been customary for years to rotate the lamp about a vertical axis while the candle-power was being determined, and the result was known as the mean, or average, horizontal candle-power; but even this determination gave an average value of the intensity in the horizontal directions only. It should be stated, however, that in comparing lamps on the basis of their horizontal candle-power, the light in directions other than the horizontal was not really ignored,

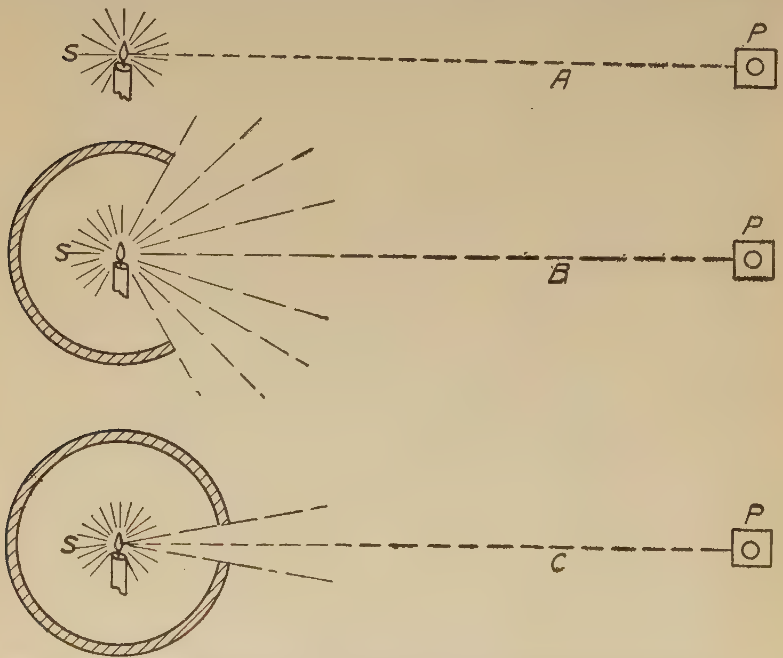

Fig. 2. Candle-Power in Direction of Photometer Is Not Changed by Partially Surrounding Light Source with Non-Reflecting Surface

for it was taken into consideration that most sources of light then in use gave off their light in about the same proportions in the different directions and that for this reason the candle-power in a single direction furnished a criterion sufficiently accurate for the needs of the time.

To carry our conception of candle-power a little further, let us assume the conditions existing in Fig. 2. At *A* we have on the left a standard candle and on the right a photometer pointed toward the candle. From what has already been stated, it is

obvious that when the photometer is balanced it will indicate an intensity of 1 candle. At *B* we have surrounded the same candle with a sphere having a moderately large opening. The inside of the sphere, we will say, has been painted a dead black so that none of the rays striking it are reflected but are absorbed and cease to be light; in other words, are thrown away so far as our experiment is concerned. In this case the photometer will still indicate an intensity of 1 candle in spite of the fact that a great deal of light has been thrown away. At *C* we have used a sphere with a much smaller opening and are therefore wasting still more of the light, but even in this case our photometer will indicate an intensity of 1 candle. In fact, our reading will be 1 candle regardless of the size of the opening, that is, regardless of the quantity of light we allow to be emitted, provided the direct rays from the candle to the photometer are not obstructed. This leads us to the important conclusion that the candle-power of a source gives no indication of the total quantity of light emitted by that source. Candle-power, we may say, is analogous to a measurement of the depth of a pool of water at a certain point on its surface—a measurement which is useful for certain purposes, but in itself gives no indication of the quantity of water in the pool.

Closely related to candle-power is *mean spherical candle-power*. The mean spherical candle-power of a lamp is simply the average of all the candle-powers in all directions about that lamp. A source giving one candle in every direction would have a mean spherical candle power of 1. If a source gave off various candle-powers in different directions, but if the average of all these candle powers were 1, this source also would have a mean spherical candle-power of 1. We must remember, however, that the infinite number of directions in which a source ordinarily emits light do not all lie in the same plane, but extend into space on all sides about the source, like the pricks of a chestnut burr.

The Lumen. We have seen from Fig. 2 that candle-power alone gives no indication of quantity* of light. It is necessary,

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* *Quantity* is here used in the sense that it indicates only a summation of flux as throughout a given solid angle about the source, and over a given area illuminated to some average value. Quantity in a more precise sense is a summation over a period of time and is measured in lumen-hours.

therefore, for us to develop a unit whereby we can measure the quantity of total flux of light emitted by a source. For this purpose let us assume a source giving 1 candle in every direction and that this source is placed at the center of a sphere painted black on the inside and having a radius of, say, 1 foot, as shown at *A*, Fig. 3. In this figure, *OR* represents an opening in the sphere through which some of the light may escape. The quantity of light allowed to escape may be varied by varying the size of the opening, with the candle-power of the source and the radius of the sphere remaining fixed; if we decide on some definite size of opening at *OR* we shall have a definite quantity of light

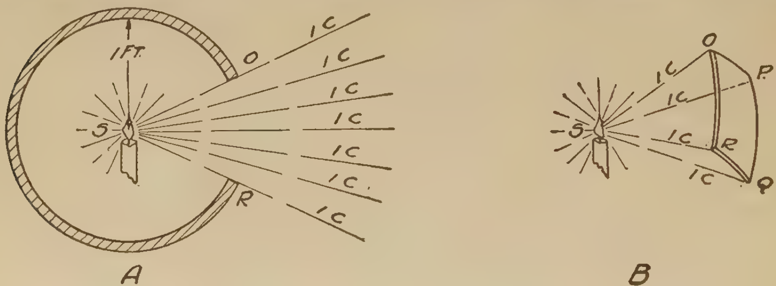


Fig. 3. Graphic Definition of Light Unit. (A) Opening OR Has Area of One Square Foot and Emits One Lumen; (B) One Lumen Falls on Surface OPQR

which we can use as our unit for measuring quantity. The simplest area or unit to assume for *OR* is 1 square foot; and if we do make this opening 1 square foot in area, the amount of light that escapes is considered to be the unit of quantity, and is called a lumen.*

If the area of *OR* is made $\frac{1}{4}$ square foot, the light escaping will amount to $\frac{1}{4}$ lumen; if the area of *OR* is doubled, the light escaping will be 2 lumens. On the other hand, if we have a uniform source of 2 candles instead of 1, 2 lumens will be emitted through an opening of 1 square foot in this particular sphere. We know by arithmetic that the total surface of the sphere having a radius of 1 foot is 12.57 square feet. In other words, removing the sphere entirely, we would have the equivalent of 12.57 openings the size of *OR*; that is, if the candle gives

* We may choose a sphere of any radius we care to, so long as we keep the size of the opening proportional—that is, its area equal to the square of the radius—and the quantity will still be one lumen.

1 candle in every direction, with the sphere removed it would give 12.57 lumens. This means that if we know the mean spherical candle-power of a lamp, by multiplying this value by 12.57 we obtain the number of lumens emitted by that lamp (a value of $12\frac{1}{2}$ is sufficiently accurate for most practical purposes). A lumen may also be defined as equivalent to the quantity of light intercepted by a surface of 1 square foot every point of which is at a distance of 1 foot from a source of 1 candle, as shown at *B*, Fig. 3.

While the foregoing definitions establish definitely the quantity of light that we use as our basic unit, it must be remembered that a lumen, in order to be a lumen, need not necessarily conform to these specifications provided the quantity of light represented is equivalent to that prescribed by the definition. A bushel might be defined as the quantity of any commodity contained in a cylindrical measure having a diameter of $18\frac{1}{2}$ inches and a height of 8 inches; however, a bushel of potatoes spread out in the field is just as much a bushel as though the shape of the pile conformed in every respect to the dimensions just named.

A Measurement Analogy. A conception of the relations just discussed may be obtained from the following simple analogy. Suppose that we have a pool of water of unknown depth, whose surface area has been found to be 5000 square inches, and it is desired to obtain a measurement of the quantity of water in the pool. At first thought, one might be tempted to measure the depth at some point by means of a yardstick. If, for example, the depth at this point were found to be 6 inches, he might say that the pool contained 6 inches of water. Obviously, such a measurement would be practically useless. A measurement of this sort corresponds to the measurement of the quantity of light given off by an illuminant as determined by its candle-power in a single direction. On second thought, the investigator might make determinations of depth at regular intervals along a straight line through the center of the pool from edge to edge and find the average depth along this line to be, say, 4 inches. To say that the pool contains 4 inches of water would hardly be more conclusive than the first determination. Such a measurement would correspond to the mean horizontal candle-power of a light source.

If the surface of the pool were divided into a large number of equal squares and measurements of depth made at the center of each square, the average depth thus found would give a definite idea of the quantity of the water in the pool since the surface area is already known. This determination corresponds to mean spherical candle-power. Now, if the average depth of the pool as just determined, is, say, $4\frac{1}{2}$ inches, the quantity of water in the pool is four and a half times 5000, or 22,500 cubic inches. To say that the pool contains 22,500 cubic inches of water is definite and positive, and this measurement corresponds to the number of lumens given off by a light source. The average depth of the pool corresponds in this analogy to the average intensity of the light source in all directions, and the area of the pool corresponds to the area of the imaginary sphere about the light source.

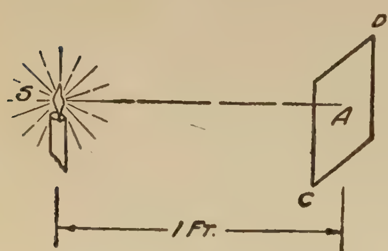


Fig. 4. Illumination at *A* Is One Foot-Candle

It might be said that the above method would be a very awkward one to employ in determining how much water there is in the pool. A more practical method would be to pump the water into some measuring vessel, as, a barrel graduated in gallons. As a matter of fact, measuring the total lumens emitted by a light source is performed in a manner analogous to the method just referred to. The mean spherical candle-power or the lumen output of a lamp may be determined at one reading by means of the sphere photometer, which is described on page 13.

The Foot-Candle. Light is a cause, and illumination the effect or result. Both the lumen and the candle are used to measure the cause, these units applying to the light source itself and not to the point where the light is utilized. To measure the illumination on a newspaper, desk, or other working plane, we employ a unit called the *foot-candle*. A foot-candle represents an intensity of illumination equal to that produced at a point on a plane which is 1 foot distant from a source of 1 candle and which is perpendicular to the light rays at that point. In Fig. 4, if the source S gives an intensity of 1 candle along the line SA, and if

A is 1 foot distant from the source, the intensity of illumination on the plane CD at the point A is 1 foot-candle. If, instead of being perpendicular to the beam, the plane AB is tilted at an angle, as shown in Fig. 5, it will be seen that the light of this beam is spread over a greater area than if the plane is perpendicular, so that the intensity of illumination on the plane is less in proportion to the ratio of the length of AB to the length of $A'B'$ or to the cosine of the angle between a perpendicular to $A'B'$ and the axis of the beam, which is the angle a. If with the plane in the position AB the illumination is 1 foot-candle and the cosine of the angle a is 0.7, the average illumination on the plane in position $A'B'$ will be only 0.7 of a foot-candle.

The foot-candle is the unit of measurement which in everyday usage is employed in computing the intensity of illumination,

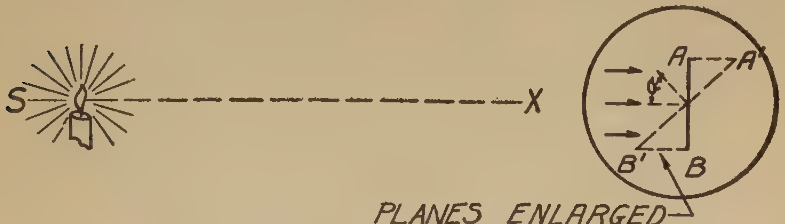


Fig. 5. Illumination on A'B' Is Less Than on AB

and a measurement which the eye, either consciously or unconsciously, is making whenever the faculty of vision is being employed; for the number of foot-candles we have on the working plane, other things being equal, determines directly whether or not there is sufficient light. A working idea of a foot-candle of illumination can be obtained by considering the intensity on a newspaper being read by the light of a candle, the paper being held approximately one foot away from the candle. The foot-candle is a unit applying to a point on a surface; by averaging the foot-candles at a number of points on a plane, we get the average intensity of illumination on that plane.

Care should be taken to avoid confusing the intensity of illumination on a surface as indicated by the foot-candles with the appearance as regards brightness of the surface. A gray surface lighted to an intensity of one foot-candle will not appear

so bright as a white one, for a greater proportion of the light falling upon the plane is absorbed and lost. The brightness of an object depends upon both the intensity of illumination on it and the percentage of light that it reflects.

Having defined the foot-candle as a unit of intensity of illumination, we are naturally interested in seeing how the intensity of illumination varies as the candle-power of the source varies, and also as the distance of the plane from the source varies. It is obvious that if in Fig. 4 instead of an intensity of 1 candle along the line *SA* we have an intensity of 2 candles, the illumination at *A* would be twice as great, and that if we have an intensity of 5 candles the illumination at *A* will be five times as great. Now, if we consider a source of 1 candle as

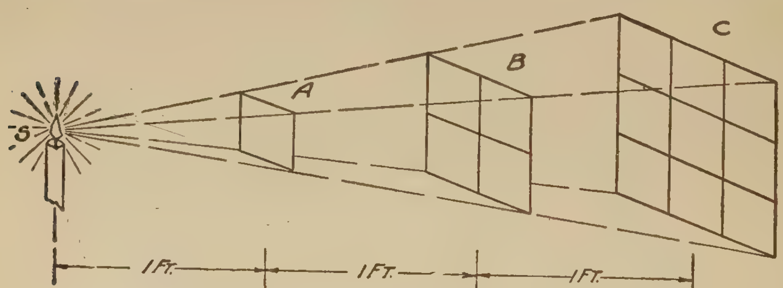


Fig. 6. Graphic Representation of Law That Illumination on Surface Varies Inversely as Square of Distance from Source to Surface

shown in Fig. 6, we know that the intensity of illumination on *A* which is 1 foot distant is 1 foot-candle. If, however, we remove the plane *A* and allow the same beam of light that formerly was intercepted by *A* to pass on to the plane *B*, 2 feet away, we find, as shown in the diagram, that this same beam of light would have to cover four times the area of *A;* and, inasmuch as we cannot get something for nothing, we should find that the average intensity on *B*, 2 feet away, would be one-fourth as high as that on *A*, 1 foot away, or one-fourth of a foot-candle. In the same way, if *B* also is removed and the same beam allowed to fall upon plane *C*, 3 feet away from the source, it will be spread over an area nine times as great as *A*, and so on; at a distance of 5 feet we should have only one-twenty-fifth of a foot-candle. From this we deduce that the intensity of illumination falls off,

not in proportion to the distance, but in proportion to the square of the distance. This relation is commonly known as the inverse-square law, and may be expressed by the following equation:

$$I=\frac{cp}{d^2},$$

if the light rays are perpendicular to the plane of illumination. Where this is not the case the formula becomes:

$$I=\frac{cp.\times\cos a}{d^2}. \qquad \text{(Fig. 5)}$$

I is illumination; *cp.* is candlepower of the source in the *direction of the plane;* d is the distance in feet between the source and the point on the plane; a is the angle between the light rays and the plane. If the plane be horizontal and h is the distance of the sourc eabove the plane, then

$$d=\frac{h}{\cos a} \qquad \text{(Fig. 7)}$$

and

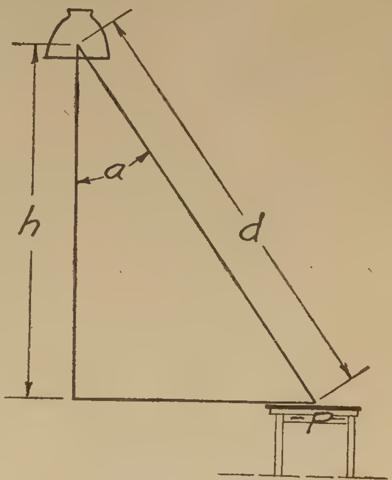


Fig. 7. Illumination on Surface Not at Right Angles to Light Rays

$$I=\frac{cp.\times\cos^3 a}{h^2}.$$

Table I gives values for $\frac{\cos^3 a}{h^2}$ for various heights (feet) of a lamp above the plane and for horizontal distances (feet) from a lamp.

Important Relation Between Foot-Candle and Lumen. If we refer back to B of Fig. 3, we see that the surface $OPQR$ is illuminated at every point to an intensity of 1 foot-candle. We also know by definition that the quantity of light falling on the plane $OPQR$ is 1 lumen. This gives us the important law that if 1 lumen is so utilized that all the light is spread over a surface of 1 square foot, that surface will be lighted to an average

TABLE I

Angle Between Light Ray and Vertical, and Intensity of Illumination in Foot-Candles on a Horizontal Plane Produced by a Source of One Candle-Power

	Horizontal Distance from Unit, Feet																		
Height of Unit above Plane, Feet	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
4	0° 0' .062500	14° 2' .057070	26° 34' .044720	36° 52' .032000	45° 0' .022100	51° 20' .015240	56° 19' .010660	60° 15' .007640	63° 26' .005590	66° 2' .004190	68° 12' .003200	70° 1' .002490	71° 34' .001980	72° 54' .001590	74° 3' .001300	75° 4' .001070	75° 56' .000900	76° 46' .000750	77° 30' .000640
5	0° 0' .040000	11° 9' .037710	21° 48' .032020	30° 58' .025220	38° 40' .019040	45° 0' .014140	50° 11' .010500	54° 28' .007850	58° 0' .005950	60° 57' .004580	63° 26' .003580	65° 34' .002830	67° 25' .002280	68° 58' .001850	70° 21' .001520	71° 34' .001260	72° 39' .001060	73° 37' .000900	74° 25' .000770
6	0° 0' .027780	9° 28' .026730	18° 26' .023720	26° 34' .019870	33° 42' .016000	39° 48' .012600	45° 0' .009820	49° 24' .007660	53° 8' .006000	56° 19' .004740	59° 3' .003780	61° 23' .003050	63° 26' .002490	66° 13' .002050	66° '48 .001700	68° 12' .001420	69° 27' .001200	70° 34' .001020	71° 25' .000880
7	0° 0' .020410	8° 8' .019800	15° 57' .018140	23° 12' .015850	29° 45' .013360	35° 32' .011000	40° 37' .008930	45° 0' .007220	48° 49' .005830	52° 7' .004730	55° 1' .003850	57° 31' .003160	59° 45' .002610	61° 41' .002180	63° 26' .001830	64° 59' .001540	66° 23' .001310	67° 37' .001130	68° 45' .000970
8	0° 0' .015630	7° 8' .015270	14° 2' .014270	20° 33' .012830	26° 34' .011180	32° 0' .009530	36° 52' .008000	41° 10' .006400	45° 0' .005520	48° 22' .004580	51° 20' .003810	53° 59' .003180	56° 19' .002670	58° 24' .002250	60° 15' .001910	61° 55' .001630	63° 26' .001400	64° 48' .001210	66° 2' .001050
9	0° 0' .012350	6° 20' .012120	12° 32' .011480	18° 26' .010540	23° 55' .009430	29° 3' .008250	33° 42' .007110	37° 52' .006070	41° 38' .005150	45° 0' .004370	48° 0' .003700	50° 42' .003140	53° 8' .002670	55° 18' .002280	57° 15' .001960	59° 3' .001680	60° 38' .001460	62° 6' .001260	63° 26' .001100
10	0° 0' .010000	5° 43' .009850	11° 19' .009430	16° 42' .008790	21° 48' .008010	26° 34' .007160	30° 58' .006310	35° 0' .005500	38° 40' .004760	41° 59' .004110	45° 0' .003540	47° 43' .003050	50° 11' .002630	52° 26' .002270	54° 28' .001960	56° 19' .001710	58° 0' .001490	59° 32' .001300	60° 57' .001150
11	0° 0' .008260	5° 12' .008160	10° 18' .007870	15° 15' .007420	19° 59' .006860	24° 27' .006230	28° 37' .005590	32° 28' .004960	36° 2' .004370	39° 17' .003830	42° 16' .003350	45° 0' .002920	47° 30' .002550	49° 46' .002230	51° 50' .001950	53° 45' .001710	55° 30' .001500	57° 6' .001320	58° 34' .001170
12	0° 0' .006940	4° 46' .006870	9° 28' .006680	14° 2' .006340	18° 26' .005930	22° 37' .005460	26° 34' .004970	30° 15' .004480	33° 42' .004000	36° 52' .003560	39° 48' .003150	42° 31' .002780	45° 0' .002460	47° 17' .002170	49° 24' .001910	51° 20' .001690	53° 8' .001500	54° 49' .001330	56° 19' .001190
13	0° 0' .005920	4° 24' .005870	8° 45' .005710	13° 0' .005470	17° 6' .005170	21° 2' .004810	24° 46' .004470	28° 18' .004040	31° 34' .003660	34° 42' .003290	37° 34' .002950	40° 14' .002630	42° 44' .002350	45° 0' .002000	47° 6' .001870	49° 5' .001660	50° 54' .001480	52° 36' .001330	54° 10' .001190
14	0° 0' .005100	4° 5' .005060	8° 8' .004950	12° 6' .004770	15° 57' .004540	19° 39' .004260	23° 12' .003960	26° 34' .003650	29° 45' .003340	32° 44' .003040	35° 32' .002750	38° 9' .002480	40° 37' .002230	42° 53' .002010	45° 0' .001800	46° 58' .001620	48° 49' .001460	50° 31' .001310	52° 7' .001180
15	0° 0' .004440	3° 49' .004420	7° 36' .004330	11° 19' .004190	14° 56' .004010	18° 26' .003800	21° 48' .003560	25° 1' .003310	28° 4' .003050	30° 58' .002800	33° 42' .002560	36° 15' .002330	38° 40' .002120	40° 55' .001920	43° 3' .001740	45° 0' .001570	46° 51' .001420	48° 34' .001290	50° 11' .001170
16	0° 0' .003910	3° 35' .003880	7° 8' .003820	10° 37' .003710	14° 2' .003570	17° 25' .003390	20° 33' .003210	23° 38' .003000	26° 34' .002800	29° 23' .002590	32° 0' .002380	34° 30 .002190	36° 52' .002000	39° 6' .001830	41° 10' .001670	43° 9' .001520	45° 0' .001380	46° 45' .001260	48° 22' .001150
17	0° 0' .003460	3° 22' .003440	6° 42' .003390	10° 0' .003310	13° 15' .003190	16° 24' .003060	19° 26' .002900	22° 23' .002740	25° 12' .002560	27° 54' .002390	30° 28' .002220	32° 54' .002050	35° 13' .001890	37° 24' .001740	39° 29' .001590	41° 25' .001460	43° 16' .001340	45° 0' .001220	46° 38' .001120
18	0° 0' .003090	3° 11' .003070	6° 20' .003030	9° 28' .002970	12° 32' .002870	15° 32' .002760	18° 26' .002640	21° 14' .002500	23° 55' .002360	26° 34' .002210	29° 3' .002060	31° 26' .001920	33° 42' .001780	35° 49' .001650	37° 52' .001520	39° 48' .001400	41° 38' .001290	43° 22' .001190	45° 0' .001090
19	0° 0' .002770	3° 1' .002760	6° 0' .002730	8° 58' .002670	11° 53' .002600	14° 45' .002510	17° 31' .002400	20° 13' .002290	22° 50' .002170	25° 21' .002050	27° 45' .001920	30° 4' .001800	32° 17' .001670	34° 23' .001560	36° 23' .001450	38° 17' .001340	40° 6' .001240	41° 49' .001150	43° 27' .001060
20	0° 0' .002500	2° 51' .002490	5° 43' .002460	8° 32' .002420	11° 19' .002360	14° 2' .002280	16° 42' .002190	19° 17' .002100	21° 48' .002000	24° 14' .001900	26° 34' .001790	28° 49' .001630	30° 58' .001580	33° 2' .001470	35° 0' .001370	36° 52' .001280	38° 40' .001190	40° 22' .001110	41° 59' .001030
21	0° 0' .002265	2° 44' .002258	5° 26' .002236	8° 8' .002200	10° 47' .002150	13° 24' .002095	15° 57' .002014	18° 26' .001935	20° 51' .001850	23° 12' .001760	25° 28' .001668	27° 39' .001575	29° 43' .001435	31° 46' .001394	33° 42' .001306	35° 32' .001222	37° 19' .001140	39° 0' .001065	40° 37' .000992
22	0° 0' .002065	2° 36' .002060	5° 10' .002047	7° 46' .002010	10° 20' .001963	12° 48' .001915	15° 15' .001852	17° 39' .001786	20° 0' .001711	22° 15' .001637	24° 30' .001553	26° 34' .001477	28° 35' .001398	30° 35' .001318	32° 36' .001240	34° 17' .001139	36° 5' .001088	37° 42' .001023	39° 20' .000955
23	0° 0' .001890	2° 29' .001890	4° 58' .001868	7° 26' .001841	9° 62' .001807	12° 16' .001763	14° 37' .001711	17° 9' .001649	19° 11' .001592	21° 22' .001525	23° 30' .001456	25° 35' .001386	27° 34' .001316	29° 29' .001246	31° 21' .001177	33° 6' .001111	34° 50' .001045	36° 28' .000984	38° 3' .000923
24	0° 0' .001736	2° 23' .001730	4° 45' .001715	7° 7' .001695	9° 30' .001662	11° 46' .001628	14° 2' .001582	16° 16' .001535	18° 25' .001480	20° 33' .001425	22° 35' .001365	24° 38' .001302	26° 35' .001240	28° 27' .001180	30° 15' .001118	32° 0' .001059	33° 40' .001000	35° 19' .000943	36° 50' .000890
25	0° 0' .001600	2° 17' .001595	4° 34' .001584	6° 51' .001565	9° 5' .001540	11° 19' .001508	13° 30' .001470	15° 39' .001427	17° 45' .001381	19° 48' .001332	21° 48' .001280	23° 45' .001226	25° 39' .001171	27° 29' .001117	29° 15' .001063	30° 58' .001009	32° 38' .000955	34° 13' .000905	35° 45' .000855

intensity of 1 foot-candle. This relation greatly simplifies the designing of a lighting installation, for once the number of square feet to be lighted and the intensity of illumination which it is desired to provide are known, it is a simple matter to find how many lumens must fall on the working plane. If, for example, it is desired to illuminate a surface of 100 square feet to an average intensity of 5 foot-candles, 500 lumens must be utilized.

Candle-Power Measurements. A sketch of the simplest type of photometer is given in Fig. 8. The essential part of this photometer is a vertical paper screen between the lamps to be compared, at the center of which is a grease spot. When the illumination on one side of the screen is greater than that on the other, the spot will on this side appear darker and on the other side lighter than the surrounding paper. By sliding the screen back and forth on the bar, a position can be found where the

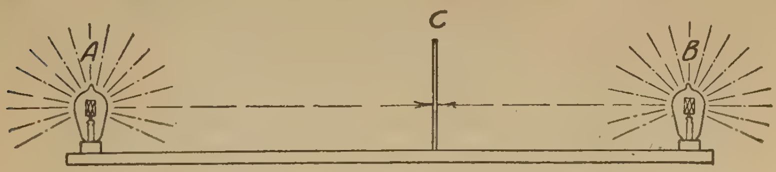


Fig. 8. Essential Parts of Horizontal Photometer

outlines of the spot will vanish and the spot itself will disappear. When this condition obtains, the illuminations on both sides of the screen are the same.

In order that both sides of the screen may be seen simultaneously, mirrors are mounted obliquely behind the screen. It will be noted that at *A*, Fig. 9, the spot as viewed in the left-hand mirror is darker than its surroundings and as viewed in the right-hand mirror is lighter than its surroundings, which indicates that the left-hand side of the screen is illuminated to a higher intensity than the right. It will also be noted that at *B* the conditions are reversed; therefore, in this case the illumination on the right side of the screen is greater than that on the left. Somewhere between these two positions is a position at which the spot will cease to be visible, as shown at *C*.

The intensities of illumination on both sides of the screen at *C* are equal. Now, since we have a relation between the

intensities of illumination that the two lamps being compared are able to produce, we can reason back as to the relation between the candle-powers given, respectively, by lamps *A* and *B*, Fig. 9. The scale of the photometer shows us that at a distance of 60 inches the lamp *A* produces an illumination equal to that which the lamp *B* can produce at a distance of 40 inches. At first thought we might say that *A* must give $\frac{3}{2}$ as great a candle-power as *B*, but recalling the inverse-square law already referred to, which states that the intensity of illumination varies inversely

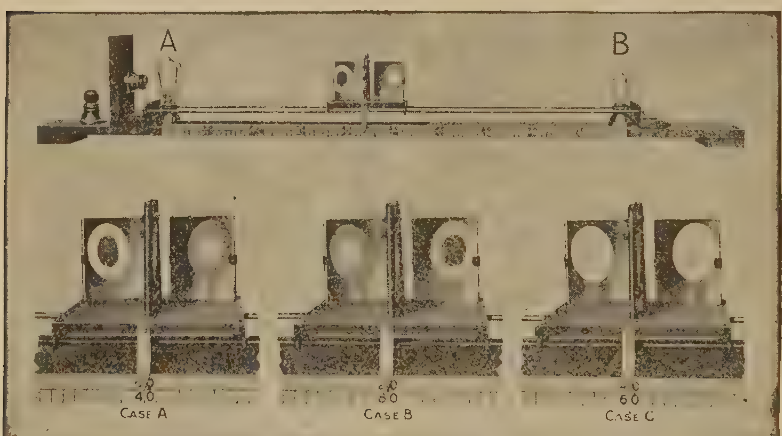


Fig. 9. Photometer and Screens. Case A, Screen at Left of Balance Point; Case B, Screen at Right of Balance Point; Case C, Screen at Balance Point

as the square of the distance, or, what is the same thing, that the candle-power necessary to produce a given illumination varies as the square of the distance from the source to the plane, we see that the ratio of the candle-power of *A* to that of *B* instead of being 3 to 2 is 3^2 to 2^2, or 9 to 4. The horizontal candle-power of *A*, therefore, is two and one-fourth times that of *B*. If *B* is a lamp of some known candle-power, the candle-power of *A* is determined by multiplying the candle-power of *B* by $2\frac{1}{4}$. The general rule, then, is that the candle-powers of two lamps on a photometer are to each other as the squares of the distances from each to the screen are to each other. For accurate photom-

etry, the grease-spot screen is no longer in use, but the newer and more accurate photometers are the same in principle.

The simple bar photometer measures candle-power in one direction only. If the lamp being measured is rotated about its axis, its mean horizontal candle-power is obtained. In like manner if the vertical axis of the lamp being measured is tipped and the lamp rotated on this axis, the average candle-power at any angle can be determined.

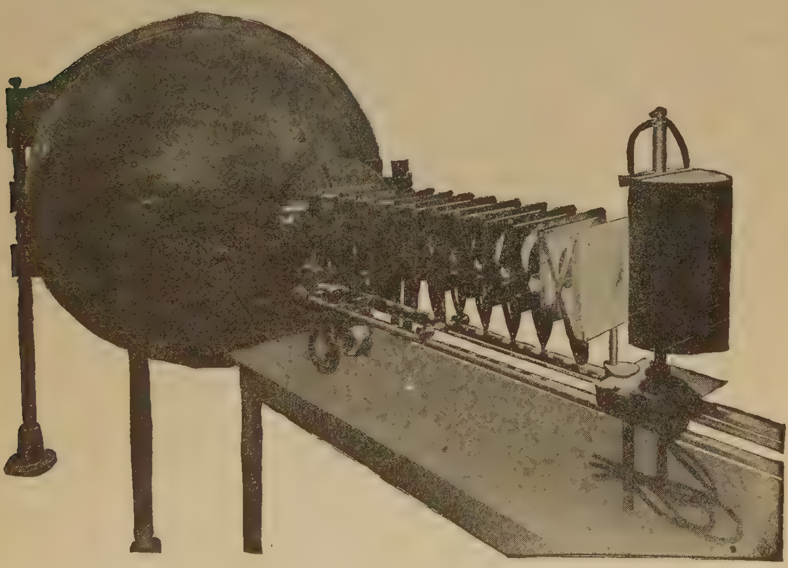


Fig. 10. Sphere Photometer

Another form of photometer, known as the sphere photometer, or Ulbricht sphere, is shown in Fig. 10. In this photometer the lamp to be measured is placed at the center of a large sphere the inside of which is painted flat white.' In this sphere is a small window of milk glass. The candle-power emitted by this window is compared with the candle-power of a standard lamp. The candle-power of the window computed as above is directly proportional to the mean spherical candle-power or the total lumen output of the lamp in the sphere, so that multiplying this candle-power by a constant factor which has been determined for this particular sphere gives the total lumen output direct.

Thus at one reading the mean spherical candle-power or the total lumen output of a lamp can be determined. A more detailed discussion of various types of photometers is given on pages 190 to 202.

Foot-Candle Measurements. It will be noted that in measuring the *candle-power* of light sources as discussed above, we balance the *illumination* on opposite sides of a screen. Often, however, we are interested in the illumination itself, that is, the foot-candle intensity which is being supplied over any given area, and care very little about the candle-power of the sources which supply the illumination. If we calculate the different foot-candle intensities to which one side of the screen of a photometer is illuminated when the distance between the screen and the standard lamp is varied, and then place the screen so that the illumination we wish to measure falls upon the opposite side of the screen, the balance of the photometer will give us a measurement of the foot-candle intensity. The differences between photometers used for measuring candle-power and those used for measuring foot-candles are chiefly those of form and calibration.

An instrument called the *foot-candle meter* has recently been designed to measure foot-candle intensities quickly and with a fair degree of accuracy. It is very simple in operation, so light that it can easily be carried about, and so small that readings can be taken in very restricted spaces. The instrument is shown in Fig. 11. In operation, it is placed upon or adjacent to the surface on which a measurement of the foot-candle intensity is desired. A lamp within the box illuminates the under side of the screen to a much higher intensity at one end than at the other. The illumination which it is desired to measure is, of course, practically uniform over the entire scale. Closely spaced translucent dots, which serve the same purpose as the grease spot in the simple bar photometer, extend from end to end of the scale. If the illumination on the scale from the outside falls within the measuring limits of the meter (0.5–25 foot-candles) the spots will appear brighter at one end of the scale than at the other, and at the point where the spots are neither brighter nor darker than the white-paper scale the illuminations from within and from without are equal. The scale is accurately calibrated

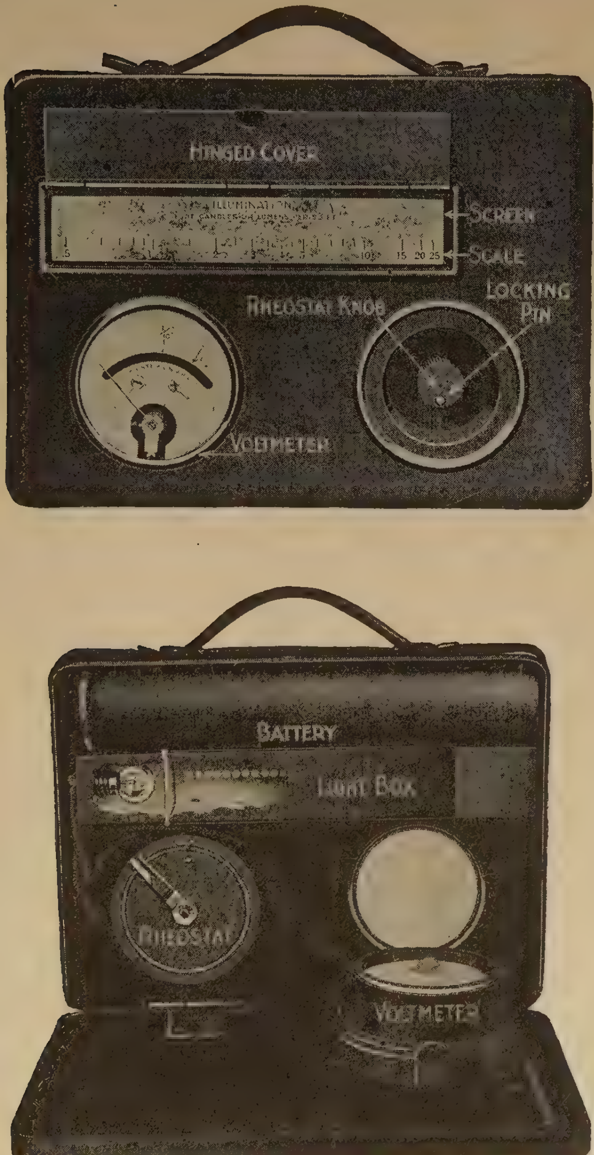


Fig. 11. Portable Foot-Candle Meter

with the lamp within the box burning at a certain definite voltage. A voltmeter and rheostat permit the operator to adjust the lamp voltage to that at which the instrument was originally calibrated. The energy is supplied from small dry cells.

This instrument is proving very serviceable for "checking up" installations to ensure, for example, that the illumination is ample when the lighting equipment is in first-class shape and to see that it is not allowed to fall below a desirable value owing to improper care being given to the lighting system.

Candle-power Distribution Curves. The calculation of illumination intensities in accordance with the formula on page 9, commonly known as the "point by point" method, required that the candle-power of the source at various angles (a) should be known and to this end the use of the polar-distribution curve, which indicated at a glance the candle-power of the lamp in all directions, was generally adopted. The greater simplicity and accuracy of the lumen method of computation has resulted in the "point by point" method falling into disuse, and distribution curves are now employed principally for comparing the suitability of reflectors for use in a given location from the standpoints, particularly, of light distribution and light absorption.

Figure 12 represents three methods of showing the manner in which the candle-power of a unit measured at different angles can be recorded. The value at any angle represents the average candle-power of the source at that angle as the source rotates about its vertical axis. At the left of the figure the data are given in tabular form; at the center and the right they are plotted to polar co-ordinates. Distribution curves are used simply as a graphical method for presenting the data given in the table on the left. All have exactly the same meaning. A distribution curve is a graphical—not a pictorial—representation of the light distribution from a source, although its general shape might convey the contrary impression. It is simply a convenient engineering method of presenting tabulated data graphically.

The area of a distribution curve is not a criterion of the total amount of light emitted by a source. In Fig. 13, both curves shown are taken from units giving exactly the same total lumens with different distributions of candle-power; although curve *B*

appears to represent much more light than curve A, the amount of light given off is the same in each case.

A common error in regard to distribution curves is to assume that simply taking the arithmetical average of the candle-powers at different angles as shown on the distribution curve will give the mean spherical candle-power of the unit represented. To make the true relation clear, let us assume a Maypole set up at the middle of a hemispherical hollow and that one girl carries a streamer making an angle of 45 degrees with the vertical and another carries one making an angle of 15 degrees with the vertical. Due to the contour of the ground about the pole, both ribbons will be of the same length. Now, keeping our candle-power distribution curves in mind, let us assume that the top of

ANGLE	CANDLE-POWER	ZONE	LUMENS
0	142.0		
5	148.0	0-10	14
15	161.0	0-20	60
25	178.0	0-30	142
35	183.0	0-40	257
45	181.0	0-50	397
55	165.0	0-60	545
65	108.0	0-70	652
75	44.1	0-80	699
85	5.1	0-90	704
90			

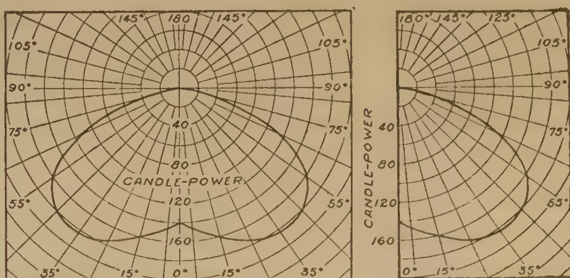


Fig. 12. Three Methods of Recording Candle-Power Distribution Data

the pole is the light source under consideration and that the length of each streamer represents the candle-power in its particular direction. It is obvious that in order to make one revolution about the pole, the girl holding the 45-degree streamer must travel a much greater distance than the other. In other words, she makes a bigger contribution to the general effect produced by the Maypole. In fact, because of the greater circle she must describe, she has to do 2.7 times as much work as the girl carrying the 15 degree streamer. In the erroneous use of a distribution curve just referred to, only the length of the ribbon is taken into consideration. From our analogy it is apparent that the zone of travel of the ribbon, or the complete zone in which the candle-power at a given angle is effective, must also be taken into account. Just as in our Maypole the girl taking the 45-degree

circle does 2.7 times as much work as the girl in the 15-degree circle, so the quantity of light necessary to maintain an intensity of one candle at the 45-degree angle contributes 2.7 times as much to the total light output of the lamp as the quantity of light required to maintain one candle at 15 degrees. In other words, the farther up from the vertical and toward the horizontal the candle-power shown on the distribution curve, the more weight it must be given as regards its contribution to the total quantity of light emitted by the source.

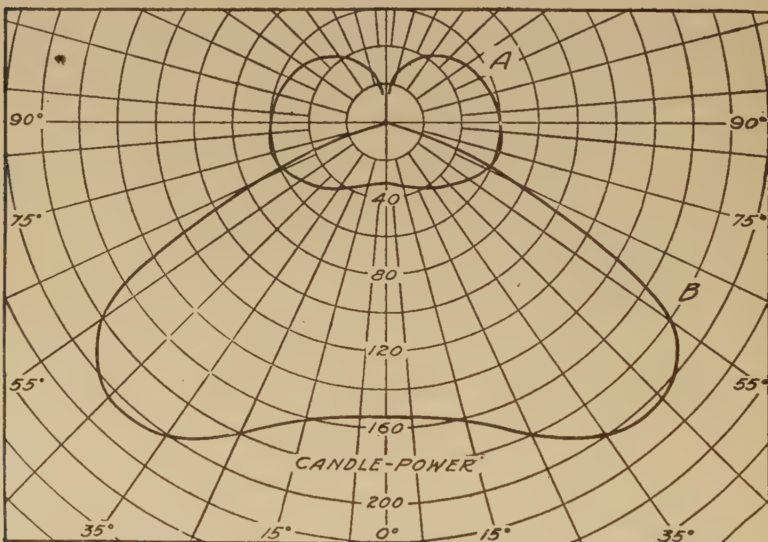


Fig. 13. Area of Distribution Curve Is Not Criterion for Judging Light Output
Curves *A* and *B* Represent Equal Light Outputs

In computing the total flux of light, we usually find it convenient to calculate for zones of 10 degrees, and it is sufficiently accurate for most purposes to assume that the candle-power value at the center of each 10-degree zone represents the average candle-power of the zone. If we go back to the uniform source of one candle-power contained in a sphere having a 1-foot radius and divide the surface of this sphere into 10-degree zones, Fig. 14, then it is evident that since the intensity of light on all parts of the surface of this sphere is 1 foot-candle, the number of lumens

falling within any zone is numerically equal to one times the area of the surface of that zone in square feet.

$$\text{Lumens} = \text{foot-candles} \times \text{square feet}$$

Again, if we place in the sphere a source whose candle-power distribution curve shows an average of 18 candle-power in the 80–90 degree zone, then the total lumens emitted by the source in that zone equals 18 times the area of the zone in square feet. In other words, to find the lumens emitted in any zone when the

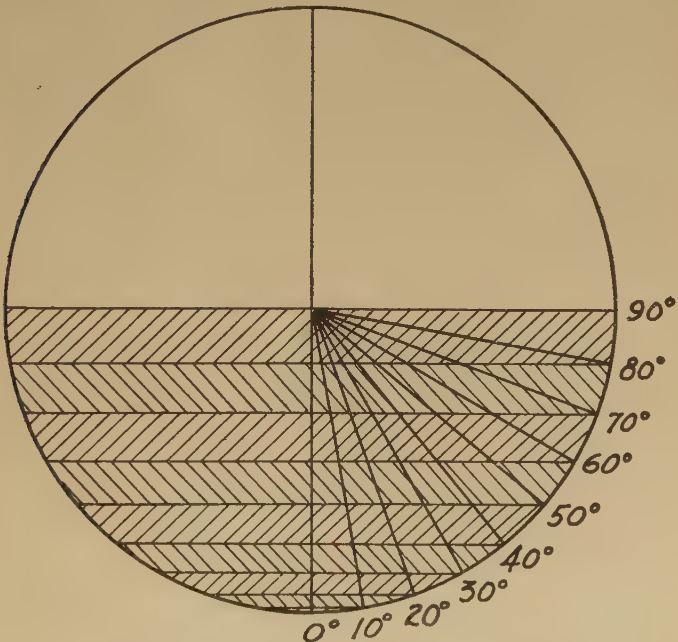


Fig. 14. Surface of Sphere Divided into 10-Degree Zones

candle-power is known, simply multiply the average candle-power directed into that zone by the area in square feet of that zone on a sphere of 1 foot radius. Table II gives the areas of these zones (the multiplying factors) for each 10 degrees.

To use these factors with the curve of any light unit, we take first the candle-power at 5 degrees and multiply it by the 0–10 degree factor to obtain lumens in the 0–10 degree zone; we take the candle-power at 15 degrees and multiply it by the 10–20

TABLE II

Areas of Zones

Zone		Area
0°–10°	170°–180°	0.0954
10°–20°	160°–170°	0.283
20°–30°	150°–160°	0.463
30°–40°	140°–150°	0.628
40°–50°	130°–140°	0.774
50°–60°	120°–130°	0.897
60°–70°	110°–120°	0.992
70°–80°	100°–110°	1.058
80°–90°	90°–100°	1.091

degree zone factor to obtain the lumens in the 10–20 degree zone, etc. The total lumens for any large zone, for example, in the lower hemisphere, is the sum of the lumens thus determined in all of the 10-degree sections.

A short-cut graphical method of determining the flux in any 10-degree zone is as follows: First measure the horizontal distance between the vertical axis and the point where the candle-power curve crosses the center of the zone under consideration. Then lay off this distance on the candle-power scale to which the curve is plotted. By adding 10 per cent to this figure, we obtain a value which represents the lumens in that zone. Where it is desired to obtain the summation of the lumens in a number of 10-degree zones, for example, from 0 degrees to 60 degrees, it is convenient to mark off these horizontal distances (to the center of each 10-degree zone) successively on the edge of a sheet of paper, Fig. 15. The value for the total lumens is then

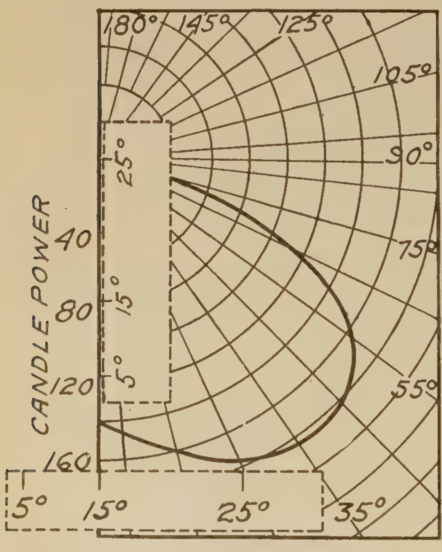


Fig. 15. Method of Finding Summation of Lumens in Number of 10-Degree Zones

found by simply laying off the total length on the candle-power scale and adding 10 per cent to the result.

In Fig. 15 it will be found, for example, that the sum of the distances laid off for 5, 15, and 25 degrees is equivalent to a reading of approximately 130 on the candle-power scale. The sum of the lumens in the 0–10, 10–20, and 20–30 degree zones (the 0–30 degree zone) is therefore 130 plus 10 per cent, or 143 lumens. This method depends for its accuracy upon the fact (which is susceptible of mathematical proof) that the area of any 10-degree zone on a unit sphere is very nearly equal to 1.1 times the mean radius of the zone in feet (1.098 times, to be exact). The proof of this theorem is beyond the scope of this volume.

DEFINITIONS*

Candle is the unit of luminous intensity maintained by the national laboratories of France, Great Britain, and the United States (often termed "international candle").

Candle-power (c-p.) is luminous intensity expressed in candles.

Lumen (1) is the unit of luminous flux equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candle-power.

Foot-candle is a unit of illumination equal to one lumen per square foot.

Lux is a unit of illumination equal to one lumen per square meter.

Performance curve is a curve representing the behavior of a lamp in any particular—candle-power, consumption, etc.—at different periods during its life.

Characteristic curve is a curve expressing a relation between two variable properties of a luminous source, as candle-power and volts, candle-power and rate of fuel consumption, etc.

Horizontal distribution curve is a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

Vertical distribution curve is a polar curve representing luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit and with the unit at the origin.

*From I.E.S. Committee on Nomenclature and Standards.

Unless otherwise specified, a vertical-distribution curve is assumed to be an average vertical-distribution curve, such as may in many cases be obtained by rotating the unit about its axis, and measuring the average intensities at the different elevations. It is recommended that in vertical-distribution curves, angles of elevation shall be counted positively from the nadir as zero, to the zenith as 180 degrees. In the case of incandescent lamps, it is assumed that the vertical-distribution curve is taken with the tip downward.

Mean horizontal candle-power (mhc.) of a lamp is the average candle-power in the horizontal plane passing through the luminous center of the lamp.

Mean spherical candle-power (sc-p.) of a lamp is the average candle-power of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

Mean hemispherical candle-power of a lamp (upper or lower) is the average candle-power of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

Mean zonal candle-power (mzc.) of a lamp is the average candle-power of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone, divided by the solid angle of the zone.

Spherical reduction factor of a lamp is the ratio of the mean spherical to the mean horizontal candle-power of the lamp.

PROBLEMS

1. If a lamp produces an intensity of 5 foot-candles on a plane 8 feet distant, what is its candle-power?

2. How many foot-candles would it produce on a plane 10 feet distant?

3. If this latter plane were inclined at an angle of 45 degrees to the light rays, what would be the intensity upon it?

4. Find the intensity of illumination at a point on a horizontal plane 8 feet below the light source whose distribution curve is given in Fig. 12.

5. Find the illumination at a point on the same plane 6 feet out from the point designated in Problem 4.

6. Find the lumens in the curve given in Fig. 62, between 0 and 40 degrees.

7. Compute the lumens in the two curves given in Fig. 13, first by the zone-factor method, and second by the graphical method, utilizing a narrow strip of paper. Compare the results.

Ans. 675 lumens

ELECTRIC ILLUMINANTS

History and Development. The history of electric lighting as an industry begins with the invention of the Gramme dynamo by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle, or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, among them Sir Humphrey Davy, who in 1810 had produced the first arc of any considerable magnitude. This arc, then called the *voltaic arc*, resulted from the use of two wood-charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but the lamps were not successful, owing chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo in 1870.

The incandescent lamp was only a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament, formed from strips of bamboo, was made in 1879. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid and the consumption of incandescent lamps alone has reached several hundreds of millions each year.

INCANDESCENT LAMPS

If a current is passed through any solid conductor, the latter gradually becomes heated, to a degree depending upon the resistance of the conductor and the strength of the current. If the conditions are such that the substance may be heated in this way until it gives out light, i.e., becomes incandescent and does not deteriorate too rapidly, we have an incandescent lamp.

Carbon was the first successful material to be chosen for this conductor, and for a long time all attempts to substitute any other substance in place of carbon failed. Within the last few years metallic filament lamps have been introduced commercially with great success, and the carbon incandescent lamp is now used only for special purposes, such as in the case of very rugged, low candle-power units operated at commercial voltages.

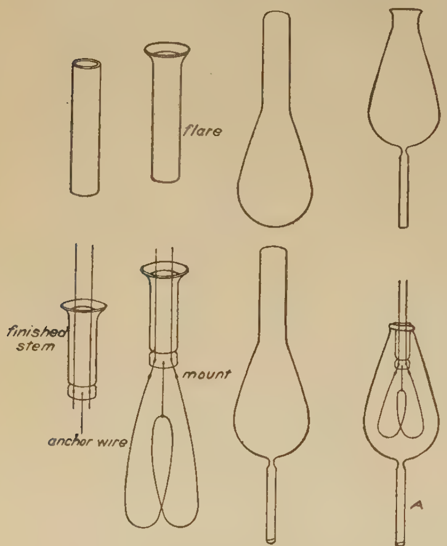


Fig. 16. Different Stages in Manufacture of Incandescent Lamp

Tungsten lamps are now used in the majority of cases, and these and other types which have proved entirely or partially successful will be treated later. The present form of carbon incandescent lamp has, however, been much improved over the first forms, and, owing to the historical importance of this lamp, the method of manufacture will be briefly considered. The several stages in the manufacture of the incandescent lamp are shown in Fig. 16.

CARBON-FILAMENT TYPE

Method of Manufacture. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform gelatine-like mass. This material is then forced,

"squirted," through steel dies into alcohol, the alcohol serving to harden the soft transparent threads, which are then dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization the material becomes hard and stiff, assuming a permanent form; after cooling, the filaments are removed, measured, and inspected.

Mounting the Filament. After carbonization the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum, which expands and contracts at the same rate as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used.

Flashing. Filaments prepared and mounted in the manner just described are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of flashing, i.e., heating the filament to a high temperature in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament to accomplish the heating. The effects of flashing are as follows:

(1) The diameter of the filament is increased by the deposited carbon, and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

(2) The surface is changed from a dull black and comparatively soft coating to a bright gray and much harder one, and the process lengthens the life and increases the efficiency of the filament.

Exhausting the Bulb. After the flashing, the filament is sealed in the bulb and the air exhausted through a tube, as shown at *A*, in Fig. 16. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. Exhaustion is necessary for several reasons:

(1) To avoid oxidization of the filament.

(2) To reduce the heat conveyed to the globe.

After the exhaustion, the tube is sealed and the lamp completed for testing by attaching the base by means of plaster of Paris or other cement.

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary, depending on the method of distribution of the power. For what is known as "parallel distribution," 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. Battery lamps operate on from 1 to 24 volts, but the vast majority of lamps for general illumination are operated at 110 volts, or thereabouts.

Efficiency. The efficiency of a lamp is the ratio between the watts input and the light output. Thus if a carbon lamp consumes $\frac{1}{2}$ ampere at 112 volts and gives 16 candle-power (200 lumens), the total wattage is $\frac{1}{2}\times 112$, which equals 56 watts; and the efficiency may be expressed as

$$56 \div 16 = 3.5 \text{ watts per candle}$$

or, preferably,

$$200 \div 56 = 3.6 \text{ lumens per watt}$$

By increasing the voltage on a lamp the total wattage, and hence the quantity of energy which must be dissipated as heat from the filament, is rapidly increased, and the temperature of the filament rises. Not only is the light input increased, but its efficiency also; for, as shown in Fig. 17, the efficiency of a lamp is very sensitive to increases in temperature. Of course, if the temperature were raised continually, a point would eventually be reached where the lamp would fail through melting of the filament. At a considerable time before this, however, we should find that lamp performance had become very unsatisfactory owing to the rapid evaporation of the filament and its reappearance as

a black coating on the inner surface of the lamp bulb. As a matter of fact, the useful life of a carbon lamp is taken as the time which elapses before the lamp has dropped 20 per cent in candle-power owing to the formation of this deposit; for it has been found less expensive to replace lamps when they have reached this point, than to continue to operate them at a decreasing efficiency. The aim of the manufacturer is to produce a lamp of the highest possible efficiency compatible with a reasonably useful life—500 to 800 hours. The life of a lamp at 3.1 watts per candle (310° C.) is about one-half of that at 3.5 watts (1300° C.).

Preparation of Gem Metallized Filament. When an ordinary filament is run at a high temperature in a lamp, there is no improvement of the filament, but it was discovered that if the

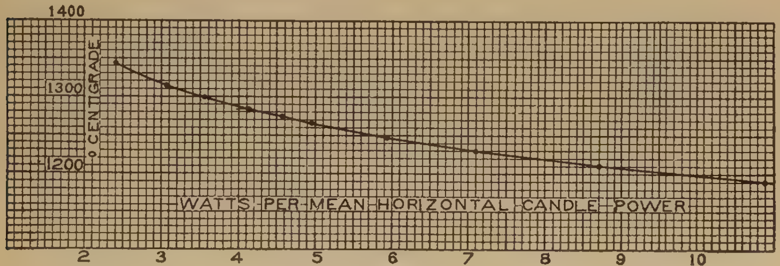


Fig. 17. Variations in Efficiency of Incandescent Lamp with Temperature

treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3000 to 3700 degrees centigrade—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and consequently higher efficiency, and still maintain a life comparable to that of a 3.1-watt lamp. Lamps with filaments so treated were called "metallized filament," or Gem, lamps. Their operating efficiency was 2.5 watts per candle, and for this reason they soon became popular in replacing the earlier 3.5- and 3.1-watt carbon lamps.

METALLIC-FILAMENT TYPE

Tantalum Lamps

Nature of Filament. The first of the metallic filament lamps to be introduced to any considerable extent commercially was the

tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and a high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon-filament lamp. On account of the comparatively low specific resistance of this material, the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 18 and 19 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per candle-power, and has a life comparable to that of the ordinary incandescent lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used in the first of the tantalum lamps. It should be noted that the life of a lamp of this type on alternating current circuits, is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits. The tantalum lamp is no longer manufactured in this country.

Fig. 18. Round-Bulb Tantalum Lamp

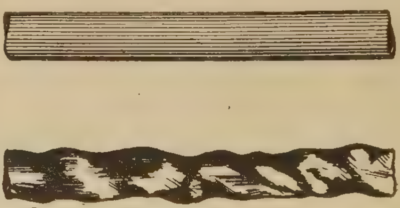


Fig. 19. Tantalum Filament before and after One Thousand Hours' Use

Tungsten Lamps

Early Methods of Preparing Filament. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point. An indirect method was originally employed in forming filaments for incandescent lamps and there were several of these methods in use. One method consisted of the use of powdered tungsten and some

binding material, sometimes organic and in other cases metallic. The powdered tungsten was mixed with the binding material, the paste squirted into filaments, and the binding material was then expelled, usually with the aid of heat. Another method of manufacture consisted of securing tungsten in colloidal form, squirting it into filaments, and then changing them to the metallic form by passing electric current through them.

Difficulties in Providing Required Durability. Tungsten lamps as formed by any of the above or similar processes, are extremely fragile, especially when cold, and the tungsten lamps in their early forms required very careful packing for shipment; were easily broken in ordinary service; could not be used satisfactorily where there was appreciable vibration; and there was a considerable reduction in candle-power with use, due to the blackening of the bulb. The first commercial tungsten lamps were produced in 1907, or thereabouts, and the development of the lamp has been continuous since that time. An efficiency of about 1.25 watts per candle-power was early realized for lamps of 100 watts rating or higher, and lamps consuming 40 and 60 watts were soon available. In 1911 a process was developed for preparing tungsten in ductile form, and wiredrawn filaments were made. These filaments proved to be much stronger than the filaments prepared by other processes, but still further development has made the present wiredrawn filaments as much more rugged than the first drawn filaments as these were stronger than the filaments made by other processes.

Wiredrawn Filaments. In the first stages of development, wiredrawn filaments were prepared only with the very greatest difficulty, but the wire can now be produced in any desired length and very uniform in cross section. The material for the filaments comes to the filament factory in the form of a concentrated tungsten ore from which tungstic oxide is obtained. This oxide is reduced by a special process requiring the agency of an electric furnace to produce tungsten metal in a powdered form. This tungsten metal is compressed into ingots about 6 inches long by $\frac{1}{4}$ inch square and again heat-treated in an electric furnace, the effect of which treatment is to strengthen the ingot and make the material a good conductor of electricity. The

material is then subjected to a temperature near the melting point in an atmosphere of hydrogen, and the result of this treatment is to weld the tungsten particles firmly together. The ingot is then heated and swaged and the process repeated until it forms a rod about .03 inch in diameter and 30 feet long. This rod is hot-drawn through special diamond dies and finally reduced to the desired size, the final drawings being made at lower temperatures or cold. Graphite is used as a lubricant during the process of drawing. The filament of a 10-watt, 110-volt lamp is about .00075 inch in diameter, a remarkably fine wire. The rest of the manufacture of the tungsten lamp is not unlike that of the carbon incandescent lamp already described.

Although titanium, zirconium, and iridium have been successfully employed for the filaments of incandescent lamps, only tungsten is now used to any great extent in the United States. Table III gives the melting points of some highly refractory metals, including the above.

Gas=Filled Lamps. Refinements in the manufacture of tungsten-filament lamps, such, for example, as the use of chemicals in the bulb to prevent blackening, have resulted in a gradual increase in the efficiency of the unit. An economy of one watt per candle in all the larger sizes is now attained.

In 1913 was developed the gas-filled lamp, a lamp having a bulb filled with an inert gas—nitrogen or argon. This lamp under favorable conditions showed an efficiency nearly twice that of its predecessors. The function of the gas in the bulb is to retard the evaporation of the filament. This evaporation takes place rapidly in a vacuum; with the gas it is possible to run the filament much nearer to its melting point than had previously been found practicable. The disadvantage of the gas was of course that it occasioned a serious loss due to transference of heat from the filament by convection. This loss was minimized as far as possible by tightly coiling the filament, a procedure which of course was impracticable before the development of the drawn-wire filament. At the present time the loss of efficiency due to carrying away of heat by the gas in a 40-watt lamp just about offsets the gain due to higher operating temperature. In all sizes larger than this the efficiency of the gas-filled lamps is greater than for

TABLE III

Melting Point of Highly Refractory Metals

Metal	Approximate Melting Point in Degrees Centigrade
Tungsten	3080–3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Iridium	3500–4500
Carbon (not a metal)	3000

the corresponding vacuum type. In smaller sizes the vacuum lamps are preferable.

Today the tungsten-filament lamp, sold largely under the trade-mark "Mazda," has replaced the earlier types of incandescent units for almost every service. The lamps are available in various types for street lighting, flood lighting, train lighting, automobile lighting, motion-picture projection, and many other classes of service. The principal sizes and types are listed in Table IV and illustrated in Fig. 26. While the increase in efficiency of Mazda lamps is their most important advantage over earlier types, there are other points of superiority which should not be overlooked.

First, the tungsten filament as distinguished from the carbon, has a positive temperature coefficient, hence a given change in voltage does not produce so great a change in candle-power and consequently in light output, as in the case of the carbon, Fig. 20. Second, the light from the tungsten filament is whiter than that from other incandescent lamps.

Daylight Lamps. The color quality of the light from a clear-bulb lamp depends primarily upon the temperature of the filament. As the temperature increases, the light becomes of a whiter quality. At the temperature at which the filament of the Mazda B lamp is operated, the light has an excess of red and yellow rays when compared with average natural daylight. This characteristic has been present throughout the centuries in which lighting sources have evolved from the torch to the incandescent

TABLE IV

Principal Types and Sizes of Mazda Lamps

Watts	Watts per Spherical C-p.	Lumens per Watt	Total Lumens	Reduction Factor	Bulb Type	Bulb Diameter (inches)	Maximum Overall Length (inches)	Base	Standard Package Quantity	Position of Burning	Light Center Length (inches)
110–125 VOLT MAZDA B LAMPS (SCHEDULE 1) STRAIGHT-SIDE BULBS											
10	1.67	7.52	75	0.78	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	. . .
15	1.47	8.55	128	0.78	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	. . .
25	1.37	9.17	230	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	. . .
40	1.33	9.45	378	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	. . .
50	1.32	9.52	476	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	. . .
60	1.29	9.74	585	0.79	S-21	$2\frac{5}{8}$	$5\frac{1}{2}$	Med. screw	100	Any	. . .
100	1.24	10.13	1010	0.79	S-30	$3\frac{3}{4}$	$7\frac{7}{8}$	Med. sc. sk.	24	Any	. . .
110–125 VOLT MAZDA C LAMPS (SCHEDULE 1) PEAR-SHAPED BULBS											
75	1.09	11.53	865	. . .	PS-22	$2\frac{3}{4}$	$6\frac{1}{8}$	Med. screw	50	Any	$4\frac{5}{16}$
100	1.00	12.57	1260	. . .	PS-25	$3\frac{1}{8}$	$7\frac{1}{8}$	Med. screw	24	Any	$5\frac{3}{16}$
150	0.92	13.66	2050	. . .	PS-25	$3\frac{1}{8}$	$7\frac{1}{8}$	Med. screw	24	Any	$5\frac{3}{16}$
200	0.86	14.61	2920	. . .	PS-30	$3\frac{3}{4}$	$8\frac{3}{8}$	Med. screw	24	Tip down	6
300	0.78	16.11	4850	. . .	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	Tip down	7
400	0.82	15.32	6150	. . .	PS-40	5	10	Mog. screw	12	Tip down	7
500	0.78	16.11	8050	. . .	PS-40	5	10	Mog. screw	12	Tip down	7
750	0.74	16.98	12800	. . .	PS-52	$6\frac{1}{2}$	$13\frac{3}{8}$	Mog. screw	8	Tip down	$9\frac{1}{2}$
1000	0.70	17.95	18000	. . .	PS-52	$6\frac{1}{2}$	$13\frac{3}{8}$	Mog. screw	8	Tip down	$9\frac{1}{2}$
220–250 VOLT MAZDA B LAMPS (SCHEDULE 2) STRAIGHT-SIDE BULBS											
25	1.65	7.62	190	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	. . .
50	1.49	8.43	422	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	. . .
100	1.39	9.04	900	0.79	S-30	$3\frac{3}{4}$	$7\frac{7}{8}$	Med. sc. sk.	24	Any	. . .
150	1.33	9.45	1420	0.79	S-35	$4\frac{3}{8}$	$8\frac{3}{4}$	Med. sc. sk.	24	Any	. . .
250	1.20	10.47	2620	0.79	S-40	5	10	Med. sc. sk.	12	Any	. . .

TABLE IV—Continued

Principal Types and Sizes of Mazda Lamps—Continued

Watts	Watts per Spherical C-p.	Lumens per Watt	Total Lumens	Reduction Factor	Bulb Type	Bulb Diameter (inches)	Maximum Overall Length (inches)	Base	Standard Package Quantity	Position of Burning	Light Center Length (inches)
220–250 VOLT MAZDA C LAMPS (SCHEDULE 2) PEAR-SHAPED BULBS											
200	1.00	12.57	2520	...	PS-30	$3\frac{3}{4}$	$8\frac{3}{8}$	Med. screw	24	Tip down	6
300	0.92	13.66	4100	...	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	Tip down	7
400	0.86	14.61	5850	...	PS-40	5	10	Mog. screw	12	Tip down	7
500	0.85	14.78	7400	...	PS-40	5	10	Mog. screw	12	Tip down	7
750	0.82	15.32	11500	...	PS-52	$6\frac{1}{2}$	$13\frac{3}{8}$	Mog. screw	8	Tip down	$9\frac{1}{2}$
1000	0.78	16.11	16100	...	PS-52	$6\frac{1}{2}$	$13\frac{3}{8}$	Mog. screw	8	Tip down	$9\frac{1}{2}$
110–125 VOLT MAZDA C-2 LAMPS—SCHEDULE 9											
75	1.58	8.0	600	...	PS-22	$2\frac{3}{4}$	$6\frac{1}{8}$	Med. screw	50	Any	$4\frac{5}{16}$
100	1.44	8.7	870	...	PS-25	$3\frac{1}{8}$	$7\frac{1}{8}$	Med. screw	24	Any	$5\frac{3}{16}$
150	1.34	9.4	1400	...	PS-25	$3\frac{1}{8}$	$7\frac{1}{8}$	Med. screw	24	Any	$5\frac{3}{16}$
200	1.25	10.1	2000	...	PS-30	$3\frac{3}{4}$	$8\frac{3}{8}$	Med. screw	24	Tip down	6
300	1.12	11.2	3350	...	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	Tip down	7
500	1.12	11.2	5600	...	PS-40	5	10	Mog. screw	12	Tip down	7
16 CELL (28–32 VOLT) MAZDA B LAMPS FOR COUNTRY-HOME LIGHTING (SCHEDULE 8) STRAIGHT-SIDE BULBS											
‡5	1.44	8.73	44	0.79	S-14	$1\frac{3}{4}$	4	Med. screw	100	Any	...
‡10	1.37	9.17	92	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
‡20	1.29	9.74	195	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
‡40	1.24	10.13	406	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
16 CELL (28–32 VOLT) MAZDA C LAMPS FOR COUNTRY-HOME LIGHTING (SCHEDULE 8) PEAR-SHAPED BULBS											
‡50	0.90	13.96	700	...	PS-20	$2\frac{1}{2}$	$5\frac{1}{8}$	Med. screw	50	Any	$3\frac{3}{4}$
‡75	0.85	14.78	1110	...	PS-22	$2\frac{3}{4}$	$6\frac{1}{8}$	Med. screw	50	Any	$4\frac{5}{16}$
‡100	0.80	15.71	1570	...	PS-25	$3\frac{1}{8}$	$7\frac{1}{8}$	Med. screw	24	Any	$5\frac{3}{16}$

‡ Labeled watts (nominal).

TABLE IV—Continued

Principal Types and Sizes of Mazda Lamps—Continued

Labeled Watts (Nominal)	Watts per Spherical C-p.	Lumens per Watt	Total Lumens	Reduction Factor	Bulb Type	Bulb Diameter (inches)	Maximum Overall Length (inches)	Base	Standard Package Quantity	Position of Burning	Light Center Length (inches)
30–34 Volt Mazda B Lamps for Train Lighting (Schedule 7) Straight-Side Bulbs											
10	1.37	9.17	85	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
15	1.31	9.59	125	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
20	1.29	9.74	175	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
25	1.29	9.74	250	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
50	1.24	10.13	500	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
60–65 Volt Mazda B Lamps for Train Lighting (Schedule 7) Straight-Side Bulbs											
10	1.44	8.73	85	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
15	1.38	9.11	125	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
20	1.36	9.24	175	0.79	S-17	$2\frac{1}{8}$	$4\frac{5}{8}$	Med. screw	100	Any	...
25	1.36	9.24	250	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
50	1.24	10.13	500	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
30–34 Volt Mazda B Lamps for Train Lighting (Schedule 7) Round Bulbs											
10	1.44	8.73	85	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
15	1.38	9.11	125	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
20	1.36	9.24	175	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
25	1.36	9.24	250	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
50	1.22	10.30	500	0.82	G-30	$3\frac{3}{4}$	$6\frac{1}{4}$	Med. sc. sk.	24	Any	...
60–65 Volt Mazda B Lamps for Train Lighting (Schedule 7) Round Bulbs											
10	1.51	8.32	85	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
15	1.44	8.73	125	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
20	1.42	8.85	175	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
25	1.42	8.85	250	0.81	G-18$\frac{1}{2}$	$2\frac{5}{16}$	$3\frac{3}{4}$	Med. screw	100	Any	...
50	1.22	10.30	500	0.82	G-30	$3\frac{3}{4}$	$6\frac{1}{4}$	Med. sc. sk.	24	Any	...
Mazda B Lamps for Electric Street-Railway Service for Use 5 in Series on 525, 550, 575, 600, 625 and 650 Volts (Schedule 5) Straight-Side Bulbs											
23	1.44	8.73	*214.0	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
36	1.41	8.91	*350.0	0.79	S-19	$2\frac{3}{8}$	$5\frac{1}{4}$	Med. screw	100	Any	...
56	1.32	9.52	*570.0	0.79	S-21	$2\frac{5}{8}$	$5\frac{1}{2}$	Med. screw	100	Any	...
94	1.27	9.89	*985.0	0.79	S-24$\frac{1}{2}$	$3\frac{1}{16}$	$7\frac{1}{4}$	Med. sc. sk.	50	Any	...

TABLE IV—Continued

Principal Types and Sizes of Mazda Lamps—Continued

Nominal Rated C-p.	Total Lumens	Average Volts	Average Watts	Watts per Spherical C-p.	Lumens per Watt	Bulb Type	Bulb Diameter (Inches)	Maximum Overall Length (Inches)	Base	Standard Package Quantity	Position of Burning	Light Center Length (Inches)
5.5 Amp. Mazda C Lamps—Street Series (Schedule 6) Straight-Side and Pear-Shaped Bulbs												
60	600	8.5	46.8	0.98	12.82	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
80	800	10.8	59.5	0.93	13.51	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
100	1000	13.0	71.5	0.90	13.96	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
250	2500	29.7	163.0	0.82	15.32	PS-35	4⅜	9¾	Mog. screw	24	Tip down	7
400	4000	47.4	260.0	0.82	15.32	PS-40	5	10	Mog. screw	12	Tip down	7
6.6 Amp. Mazda C Lamps—Street Series (Schedule 6) Straight-Side and Pear-Shaped Bulbs												
60	600	7.1	46.8	0.99	12.69	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
80	800	9.1	60.0	0.94	13.37	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
100	1000	10.9	72.0	0.90	13.96	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
250	2500	23.5	155.0	0.78	16.11	PS-35	4⅜	9¾	Mog. screw	24	Tip down	7
400	4000	37.1	244.0	0.77	16.32	PS-40	5	10	Mog. screw	12	Tip down	7
600	6000	55.7	368.0	0.77	16.32	PS-40	5	10	Mog. screw	12	Tip down	7
7.5 Amp. Mazda C Lamps—Street Series (Schedule 6) Straight-Side and Pear-Shaped Bulbs												
60	600	6.4	48.0	1.00	12.57	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
80	800	8.0	60.0	0.94	13.37	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
100	1000	9.6	72.0	0.90	13.96	S-24½	3 1/16	7¼	Mog. screw	50	Any	5⅜
250	2500	19.6	147.0	0.74	16.98	PS-35	4⅜	9¾	Mog. screw	24	Tip down	7
400	4000	30.5	228.0	0.72	17.45	PS-40	5	10	Mog. screw	12	Tip down	7
600	6000	45.8	344.0	0.72	17.45	PS-40	5	10	Mog. screw	12	Tip down	7
15 Amp. Mazda C Lamps—Street Series (Schedule 6) Pear-Shaped Bulbs												
400	4000	15.3	230.0	0.72	17.45	PS-40	5	12½	Mog. screw	12	Tip down	*9½
20 Amp. Mazda C Lamps—Street Series (Schedule 6) Pear-Shaped Bulbs												
600	6000	15.5	310.0	0.65	19.33	PS-40	5	12½	Mog. screw	12	Tip down	*9½
1000	10000	25.9	520.0	0.65	19.33	PS-40	5	12½	Mog. screw	12	Tip down	*9½

* Tip up-burning, 8¼ inches.

electric lamp. The influence of this characteristic is manifest in the red, brown, and amber tones which predominate in the decorations of rooms designed to appear at their best under artificial light. That a light of this quality is essential to such color schemes is evidenced by the frequent choice of amber-colored shades.

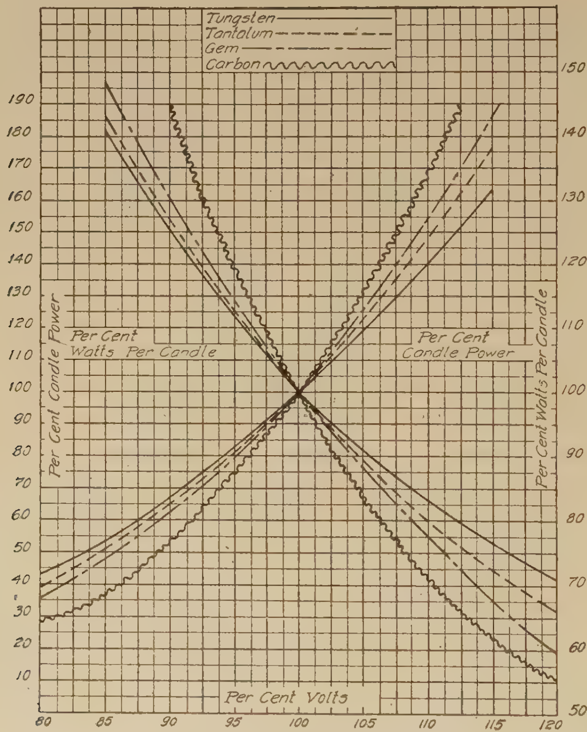


Fig. 20. Curve Showing Variation of Candle-Power and Watts per Candle Due to Change of Voltage

An artificial illuminant whose color quality is approximately the same as natural daylight is welcomed by many as opening new possibilities in interior decoration and design. Nor is this the only field for such illumination. The lighting of show windows, store interiors, and even industrial plants can be greatly improved by the use of the whiter light. It has always been possible to modify, by the use of color screens, the light of Mazda B lamps to secure any desired color, but a modification to light

of daylight quality was accompanied by a great sacrifice in efficiency. The development of the Mazda C lamp was a step toward overcoming this difficulty. Since the filament of the Mazda C lamp operates at a higher temperature, its light when unscreened is of a whiter quality than that of the Mazda B lamp, and the necessary color screen need not be so dense. The resulting decreased absorption, together with the higher efficiency of the Mazda C lamp, makes possible the production of light of approximate daylight quality at an efficiency which is not prohibitive to

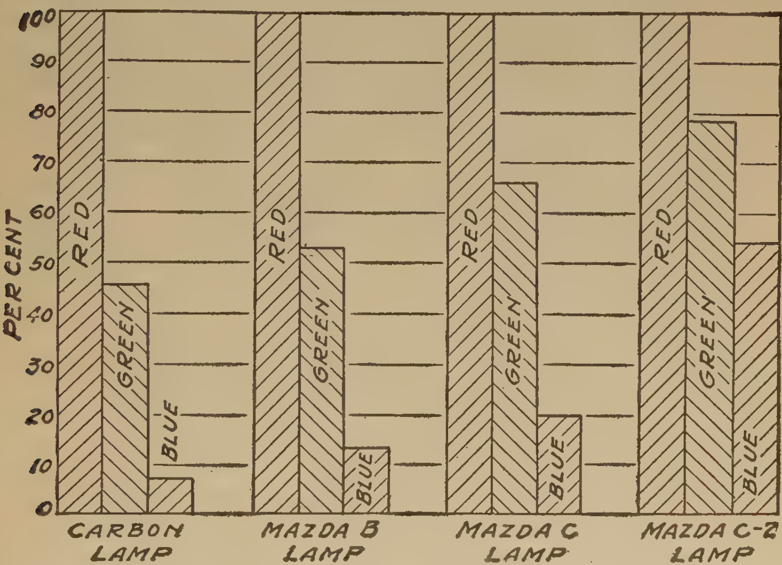


Fig. 21. Comparison of Color Quality of Light of Incandescent Lamps

its general use. The Mazda C-2 lamp has the proper screening properties incorporated in the glass of the bulb. The excess red and yellow rays of the light are absorbed, while the blue and green rays are permitted to pass through; thus a light of afternoon-sunlight quality is produced at an efficiency about equal to that of the Mazda B lamp. While the color quality of such a light is sufficiently near that of daylight to serve for general illumination, and from this standpoint is a decided improvement over the light emitted by the uncolored-bulb lamps, it is not of the proper quality to permit extremely accurate color matching.

Where an accurate duplication of north-sky light is necessary, units employing Mazda C lamps and properly designed color-screen plates should be used. The light from such units is of constant quality and therefore more dependable than the natural north sky, which varies in quality from day to day.

The diagrams of Fig. 21 show a comparison in primary color content of the light of carbon, Mazda B, Mazda C, and Mazda C-2 lamps. In this figure 100 per cent red, 100 per cent green, 100 per cent blue, is taken for average daylight, not north-sky light, which has more blue. It can be seen that a very decided improvement in the color quality of artificial light has been

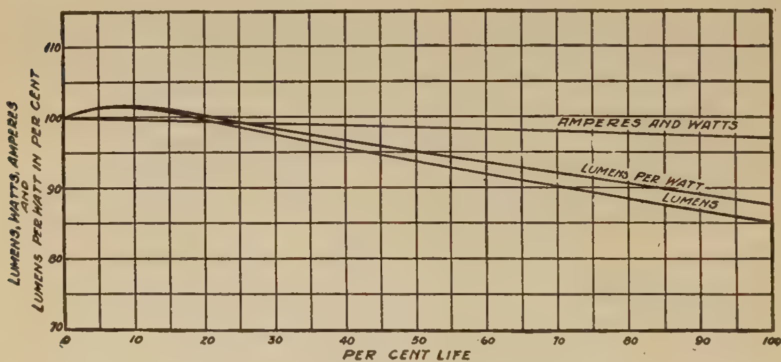


Fig. 22. Typical Performance Curves of Mazda B Lamps

effected from the time the carbon lamp was used down to the present.

Life Performance. If Mazda B lamps are operated at the voltage for which they are labeled, the lumen output at the end of their rated life usually averages not less than 85 per cent of its initial value. The decrease in wattage and current during life is represented by a practically straight-line curve showing a drop at the end of rated life of about 3 per cent. The curve showing the per cent lumens per watt follows the lumen curve closely, decreasing in value at a slightly lower rate because of the decrease of wattage with life. These curves for Mazda B and Mazda C lamps are shown in Figs. 22 and 23, respectively. Because of the convection currents set up by the gas in Mazda C lamps, the evaporated tungsten is deposited higher up in the bulb, where it

TABLE V

Result of Life Test on 100 60-Watt Mazda B Lamps

Hours Burned	0	200	400	600	800	1000	1200	1400	1600	1800
Number Lamps Remaining	100	97	94	89	77	60	39	17	3	0

does not interfere to any great extent with the transmission of light. For this reason Mazda C lamps, operated in the usual pendent position, maintain an even higher percentage of initial candle-power than do Mazda B lamps. This difference is most marked within useful angles.

The life rating of multiple Mazda lamps is determined by the average results of exhaustive tests on many groups of lamps.

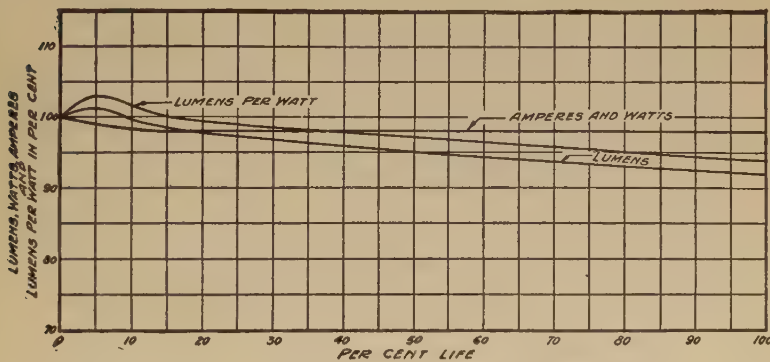


Fig. 23. Typical Performance Curves of Mazda C Lamps

Table V shows the results of a typical life test on 100 60-watt Mazda B lamps. It can be seen that of the lot of 100 lamps, 40 lamps failed before burning 1000 hours, and 60 lamps burned beyond that period. Since these data are typical, qualitatively, of the average results which may be expected from all multiple Mazda lamps used for ordinary purposes of illumination on circuits of 110 to 125 volts, it follows that in a new installation of multiple Mazda lamps, all the lamps cannot be expected to burn for the period of their average rated life and then fail simultaneously. It has been found from service experience that for a period of 4000 to 5000 burning hours after a new installation is made, there

is a variation or fluctuation in the rate of lamp renewal (the renewals per day, per week, etc.). The range of variation becomes narrower as time goes on, until the rate of lamp renewal finally becomes constant. This variation is often attributed to irregularities in lamp quality, but analysis shows that this variation follows naturally from the burn-out characteristics of incandescent lamps.

In the first several hundred hours' operation of a large installation in which all the lamps are new, a small percentage of

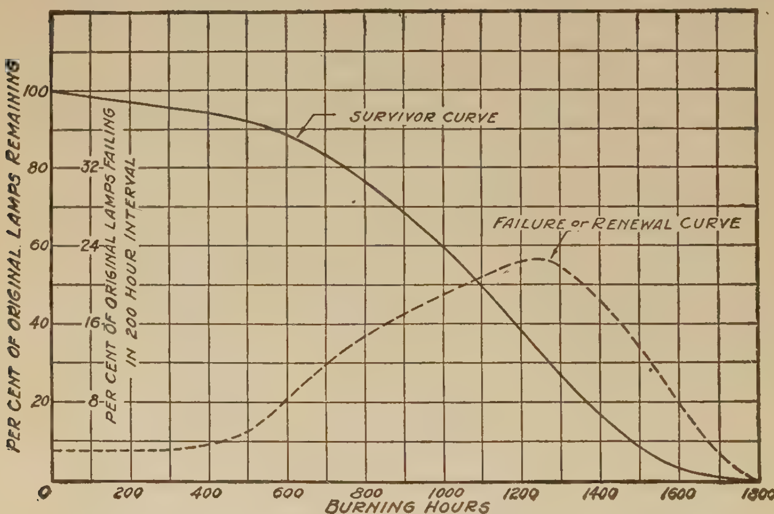


Fig. 24. Typical Survivor Curve and Corresponding Curve of Renewals

the lamps will burn out. However, as the period of burning approaches the average rated life of the lamps, the rate of burn-out will increase. The solid-line curve of Fig. 24 is a survivor curve derived from the results of the tests mentioned above, which shows the rate of burn-outs from the time the installation is first put in operation until the last original lamp has failed. It can be seen from the curve that for the first 500 hours of service the lamp failures are comparatively few, but the rate of mortality steadily increases up to a short time subsequent to the rated average life of all the lamps, 1000 hours. From this time on, the rate of mortality decreases continuously until all the initial lamps have failed.

The broken-line curve of Fig. 24 represents the variation in lamp renewals per 200-hour period for a group of lamps which have a survivor curve similar to the solid-line curve of the same figure. Obviously, the failures of the renewal lamps will occur at a somewhat later period than the failures of the original lamps. If the failures of the renewal lamps are added to the failures of the initial lamps, it can be seen that at some time, more or less closely corresponding to the peak of the dotted-line curve, there will be a peak in the total-renewal curve. The curve of Fig. 25

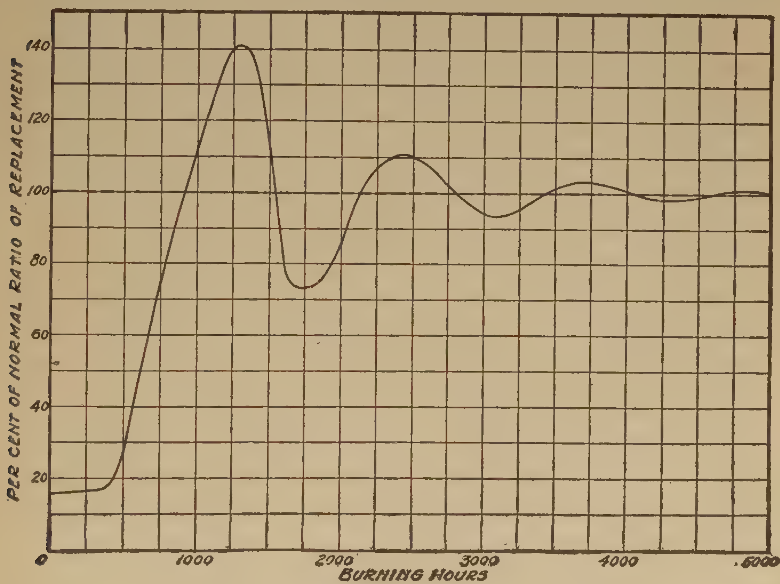


Fig. 25. Periodic Fluctuations of Renewals

presents this phenomenon. The first peak in the total-renewal curve, which is approximately 40 per cent above normal, occurs about 1300 average burning hours after the initial installation. Corresponding to the subsequent decline of the dotted-line curve of Fig. 24, the total-renewal curve shows a decided decline from the first peak, indicating that the rate of renewal may be expected to decrease to about 70 per cent of its normal value at 1750 hours. As time goes on, the oscillations of the renewal-rate curve show a decrease in range, and finally, at from 4000 to 5000 burning hours, it becomes practically constant and normal. The aver-

age renewal rate for the total period will, of course, be the same as if the renewal rate were normally constant from the beginning.

110–220 Volt Circuits. As previously stated, all multiple lamps have essentially the same operating characteristics. However, owing to the necessary difference in construction, the quality of service rendered by 220–250 volt lamps is not the equal of that rendered by the 110–125 volt lamps of the same wattage. Briefly stated, the filaments of 220–250 volt lamps are necessarily longer, and of smaller diameter, than those of 110–125 volt lamps. Owing to the longer filaments, a greater number of supports must be provided for 220–250 volt lamps. With the greater length of filament and the added number of supports, there is an increased tendency to short-circuit parts of the filament. There is also a greater tendency for the current to arc and cause an immediate failure of the lamp.

Since the filaments of the 220–250 volt lamps are of smaller diameter than those of the 110–125 volt lamps, the temperature at which they can be operated with normal life is somewhat lower than that at which the filaments of 110–125 volt lamps operate, and the light output per watt, therefore, is less (see Table III).

Where 220 volts only is available, the practice of burning 2 lamps of the 110-volt class across 220-volt lines has met with considerable favor. Under these circumstances, however, slightly less than normal life is to be expected from the lamp; for, although two new lamps usually operate satisfactorily in series, one lamp naturally fails sooner than the other, and when a replacement is made the resistance of the two lamps will be higher than that of two new lamps and less than that of two old ones, since the resistance of lamps increases with burning. Hence, the new lamp will receive slightly less than normal current and will give less than normal candle-power, while the old lamp will be forced to carry a somewhat heavier current than it would normally carry at that period of its life and will, therefore, fail earlier than it otherwise would. This, however, has its compensations, for the old lamp is not so likely to fall below 80 per cent candle-power.

A more serious disadvantage of operating two lamps in series is that the failure of either lamp means doing away with both;

thus a relatively large area is left without sufficient light, and the time of several persons may be lost while the defective lamp is being located and the replacement made. Obviously, in industrial plants and shops, accident risk under these conditions is increased over that when only one lamp is out.

Because of these factors, in the great majority of plants where 220–250-volt lamps are now used the most satisfactory and economical lighting results are to be secured by providing 110-volt potential for the lamps by placing a balancer between the 220-volt lighting feeders and running a third, or neutral, wire to the main distributing points. The purpose of the balancer is to maintain equal voltage on the two sides of the 3-wire circuit despite unequal loading. For alternating-current circuits, a simple balancer coil suffices; for direct current, a small mechanically coupled shunt or compound-wound motor set is commonly used.

Since the current which the balancer must carry is determined by the degree of unbalancing, the capacity of the apparatus required in any given case depends upon the magnitude of the lighting load and upon how nearly the conditions of installation will allow the circuits in the panel boxes to be made to balance. Obviously, the greater the number of properly connected circuits, the smaller the chance for serious unbalancing to occur. In practice, the size of the balancer installed ranges from about 10 per cent of the total connected lighting load to 20 or even 25 per cent, according to the size of the load and how well the circuits may be divided. The capacity of the balancer set as used here is in terms of the current flowing in either machine multiplied by the total impressed voltage of 220–250-volts, or, what is the same thing, the current flowing in the neutral multiplied by half the impressed voltage.

Space does not admit of a comparison between the operating cost of 110- and 220-volt lighting systems; however, in most cases this entire expense is offset by the reduced cost of lamp renewals and energy during the first year or year and a half of operation. It should be borne in mind also that where the wattage of the lamps is kept the same as before, the illumination will be increased by from 10 to 20 per cent, an improvement which is usually very

acceptable in view of the general rise in the standard of illumination.

Burning Positions for Mazda Lamps. Mazda B lamps operate equally well in all positions. Mazda C and Mazda C-2 lamps in sizes larger than 150 watts are not regularly supplied to burn in positions other than the vertical, tip down. While it is possible to modify the construction of the lamps of larger size so that they will operate fairly well in positions other than tip downward, in practically all cases it will be advisable to

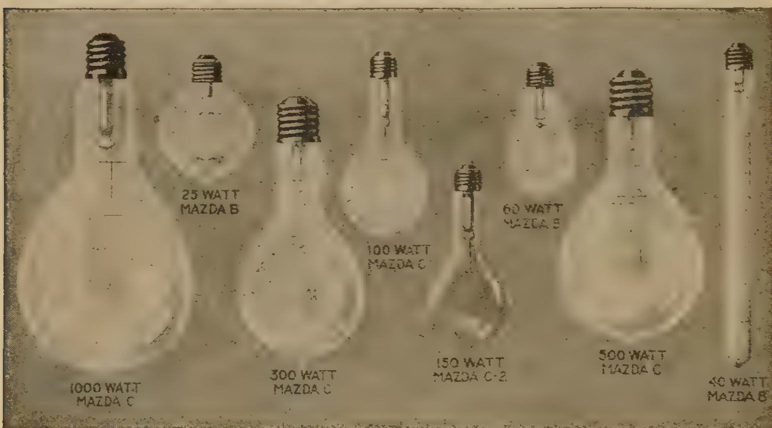


Fig. 26. Typical Mazda Lamps

modify the auxiliary equipment so that regular lamps may be utilized.

The chief types of Mazda lamps are illustrated in Fig. 26.

NERNST LAMP

The Nernst lamp is still another form of incandescent lamp, one type of which is shown in Fig. 27. The lamp is no longer manufactured, but, as it was used quite extensively at one time, a brief description is given here.

Glower. For the incandescent material of this lamp certain oxides of the rare earths were used. The oxides were mixed in the form of a paste, then squirted through a die into a string. The strings, after being subjected to a roasting process, formed the filament or *glower* material of the lamp. The more recent glowers

were made hollow instead of solid. The glowers were cut to the desired length and platinum terminals attached. The attachment of these terminals to the glowers was an important process in the manufacture of the lamp. The glowers were heated to incandescence in open air, a vacuum not being required.

Heater. As the glower is a nonconductor when cold, some form of heater was necessary to bring it up to a temperature at which it would conduct. One form of heater consisted of a porcelain tube placed just above the glower, about which a fine platinum wire was wound; the wire was coated with a cement. Two or more of these tubes were mounted directly over the glower or glowers, and served as a reflector as well as a heater.

Fig. 27. Westinghouse Nernst Multiple-Glower Lamp

The heating device was connected across the circuit when the lamp was first turned on, and it had to be cut out of circuit after the glowers became conductors in order to save the energy consumed by the heater and to prolong the life of the heater. The automatic cut-out was operated by means of an electromagnet, so arranged that current flowed through this magnet as soon as the glower became a conductor, and contacts in the heater circuit were opened by this magnet. The contacts in the heater circuit were kept normally closed, usually by the force of gravity.

Ballast. The conductivity of the glower increased with the increase of temperature—the material has a negative temperature coefficient; hence, if it were used on a constant-potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current from increasing beyond the desired value, a ballast resistance was used in series with the glower. As is well known, the resistance of iron wire increases rapidly with increase in temperature, and the resistance of a fine pure-iron wire was so adjusted that the resistance of

the combined circuit of the glower and the ballast became constant at the desired temperature of the glower. The iron wire had to be protected from the air to prevent oxidization and too rapid temperature changes, and for this reason it was mounted in a glass bulb filled with hydrogen. Hydrogen was selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

Advantages Claimed. All the parts enumerated, namely, glower, heater, cut-out, and ballast, were mounted in a suitable manner; the smaller lamps with but one glower were arranged to fit in an incandescent-lamp socket, while the larger types were constructed in special fixtures, like small arc lamps. All parts were mechanically arranged so that renewals might easily be made when necessary, and it was not possible to insert a part belonging to one type of lamp into a lamp of a different type.

MERCURY-VAPOR LAMPS

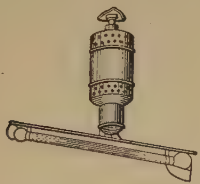
Operating Principles. The mercury-vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and is being used to a considerable extent for industrial illumination. In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup, and the connections between the lamp terminals and the electrodes are platinum where this connection passes through the glass.

The general appearance of the standard lamps and candle-power distribution curves of the more important types are given in Fig. 28.

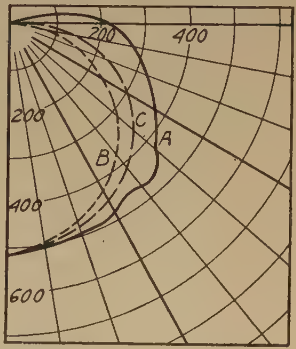
The tubes require renewal only at long intervals of from 4000-8000 hours; more properly, perhaps, the life should be stated at from 2 to 3 years, since the burning out of a tube appears to be dependent more upon the number of times that it

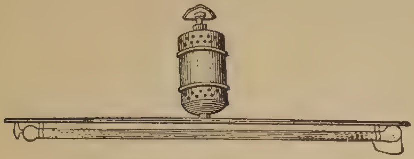
is lighted and extinguished than upon the actual hours of burning. The change in candle-power with use is illustrated in Fig. 29.

Starting the Lamp. Mercury vapor, at the start, may be formed in two ways: First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and the mercury is vaporized when the stream breaks; and second,

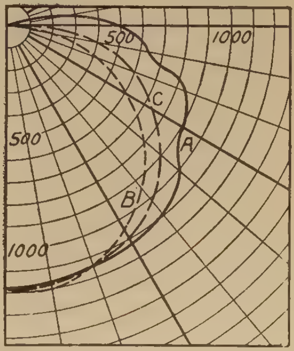


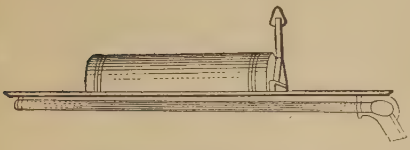
D.C. 55-Volt 3.5-Ampere. Two in Series on 100–125 Volt Circuit





D.C. 100–125 Volt 3.5 Ampere





A.C. 100–125 Volt 4.1 Ampere

Fig. 28. Cooper-Hewitt Glass Tube Mercury Vapor Lamps
Upper Diagram Refers to 55-Volt Lamp and Lower to Either Type of 100–125 Volt Lamp. Curve *A* Represents Candle-Power Distribution in Plane Perpendicular to Axis of Tube; Curve *B* Represents Candle-Power Distribution in Plane Parallel to Axis of Tube; Curve *C* Represents Mean of Curves *A* and *B*

by means of a high inductance and a quick-break switch, a very high voltage, sufficient to pass a current from one electrode to the other through the vacuum, is induced and the conducting vapor is formed. Tilting is brought about automatically in the more recent types of lamp. Fig. 30 shows the connections for starting automatically two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

TABLE VI

Candle-Power Characteristics of Cooper-Hewitt Mercury-Vapor Lamps*

Rating of Lamp in Average Watts	Voltage	Type	Length of Tube in Inches	Mean Lower Hemispherical C-p.	Watts per Mean Lower Hemispherical C-p.	Total Lumens	Lumens per Watt
	Lamps for Alternating-Current Circuits						
210	100–125	E	35	400	0.53	3179	15.14
380	100–125	F	50	800	0.48	6283	16.53
	Lamps for Direct-Current Circuits						
192	Series on 100–125	H	21	300	0.64	2388	12.43
385	100–125	HH	21	600	0.64	4712	12.23
385	100–125	K	45	700	0.55	5529	14.36
220	100–125	L	35	400	0.55	3142	14.28
385	100–125	P	50	800	0.48	6283	16.31
	Quartz Lamps for Direct-Current Circuits						
726	200–240	Z	4	2400	0.3	18839	25.96

**Data furnished by Cooper-Hewitt Electric Co.*

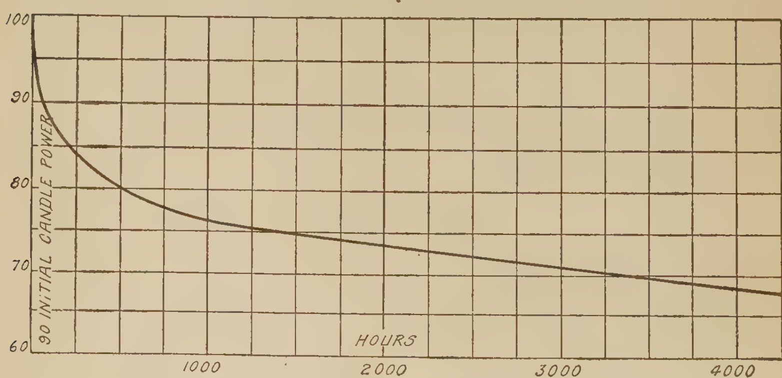


Fig. 29. Candle-Power Performance of Two 21-Inch 55-Volt 3.5-Ampere Mercury-Vapor Lamps

Applications. The mercury-vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes, as there is an entire absence of red rays; in fact,

the light is practically monochromatic. The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out, and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color, the application of this lamp is limited to the lighting of shops, offices, and drafting rooms. It is used to a considerable extent in photographic work on account of the chemical properties of the light. Special reactances must be

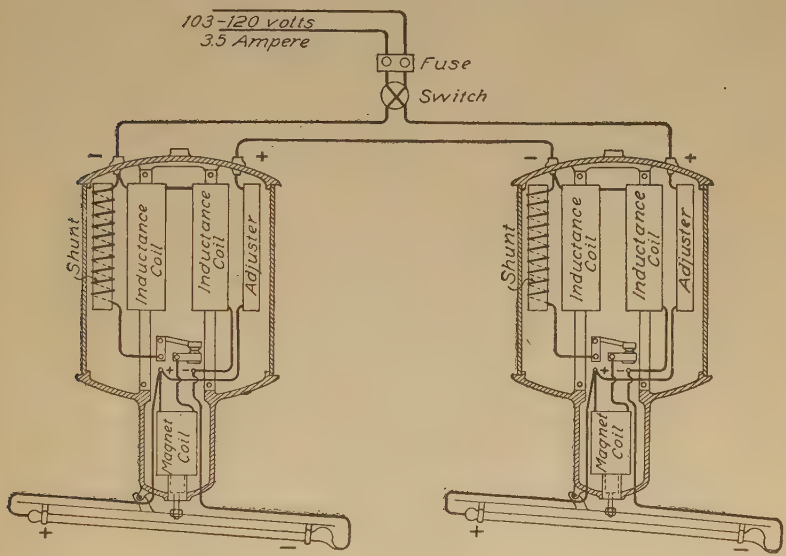


Fig. 30. Wiring Diagram for two "Type H" Cooper-Hewitt Automatic Lamps in Series

provided for a mercury arc lamp operating on single-phase, alternating-current circuits. These alternating-current lamps have practically the same efficiency as the direct-current lamps.

The candle-power characteristics of these lamps are shown in Table VI.

Quartz Mercury-Vapor Lamp

Comparison with Ordinary Mercury Lamp. *Increase in Voltage and Temperature.* Since in the mercury-vapor lamp the arc at the electrode gives practically no light but consumes some energy and the bulk of the light is given by the mercury-vapor column, the efficiency of the mercury-vapor tube as a light-giving

source is improved by using very long tubes, as in the standard lamp; or the performance may be improved by using a higher voltage per unit length of the tube than is ordinarily employed, provided a tube can be made to withstand the higher temperatures reached with this higher voltage per unit length. The vapor pressure is low in the regular glass tube, seldom over one-eighth inch of mercury pressure, but if the tubes are made of quartz, which is capable of standing a much higher temperature than ordinary glass, the drop in potential per inch of tube length can be increased to 30 or more times that allowable with glass tubes.

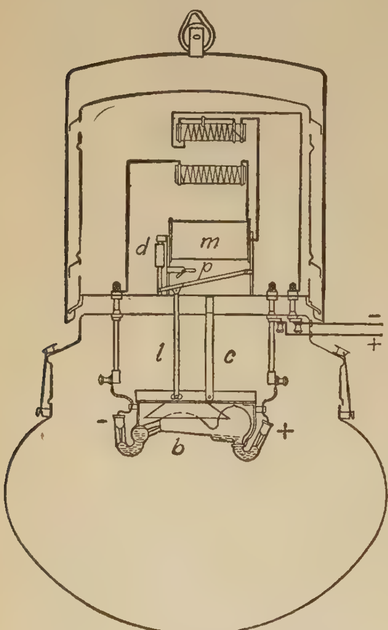


Fig. 31. Diagram of Cooper-Hewitt Quartz Lamp

White Color of Light. When operated in this manner the mercury-vapor actually becomes incandescent and the character of the light given by the lamp is changed, red and orange rays being added to the yellow, blue, green, and violet of the ordinary mercury-vapor lamp. The pioneer work on this type of lamp was done in Germany, but it has since been taken up in the United States and the lamp has been developed into a commercial form.

Construction and Operation. The light-giving element of the commercial lamp is a short tube of quartz containing mercury vapor. The necessary mechanism for starting and controlling the lamp is placed in a hood above the quartz tube and the tube itself is surrounded by a glass globe, partly for the purpose of cutting off the ultra-violet light given by the mercury vapor and not screened off by the quartz tube. The details of a Cooper-Hewitt quartz lamp are illustrated in Fig. 31, and the general appearance of one of these lamps is shown in Fig. 32. Referring to Fig. 31, which illustrates the mechanism: *b* is the quartz tube

or burner placed in a suitable holder which is pivoted in a support *c* and attached to the lever *l*; *l* is linked to the movable iron armature *m*; *d* is a dashpot; *p* is a small permanent magnet installed for the purpose of locking the mechanism and preventing its operation if the lamp should be connected in the circuit with a wrong polarity. Closing the lamp switch automatically tips the quartz tube and starts the lamp in operation. Table VI gives some operating data for the Cooper-Hewitt quartz lamps. They are available for direct current only.

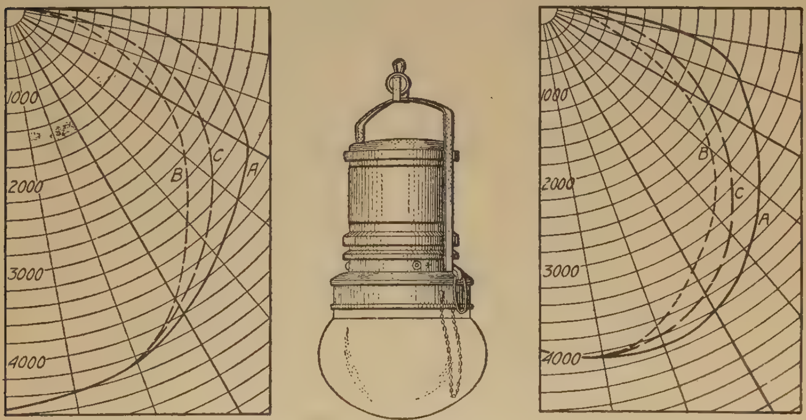


Fig. 32. Hemispherical Candle-Power Distribution Curves for Cooper-Hewitt Quartz Lamps with Different Styles of Globes—Curves at Left for Reflector and Clear Glass Globe; Curves at Right for Reflector and Diffusing Globe

TUBE LIGHTING

Moore Tube Light. *Use of Geissler-Tube Principle.* The Moore light made use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount of research work and a number of interesting installations have been made. Those for general lighting were constructed by welding together standard lengths of $1\frac{3}{4}$-inch glass tubing until the desired total length of luminous source was reached, ordinarily from 40 to 200 feet. In order to provide an electrical discharge through this tube it was customary to lead both ends of the tube to the high-tension terminals of a transformer, Fig. 33, the low-tension side

of which was connected to the alternating-current lighting mains. This transformer was constructed so that the high-tension terminals were not exposed and the current was led into the tube by means of platinum wires attached to carbon electrodes. The electrodes were about 8 inches in length. The ends of the tube and the high-tension terminals were enclosed in a steel casing so as effectually to prevent anything from coming in contact with the high potential of the system.

Color of Light. The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted

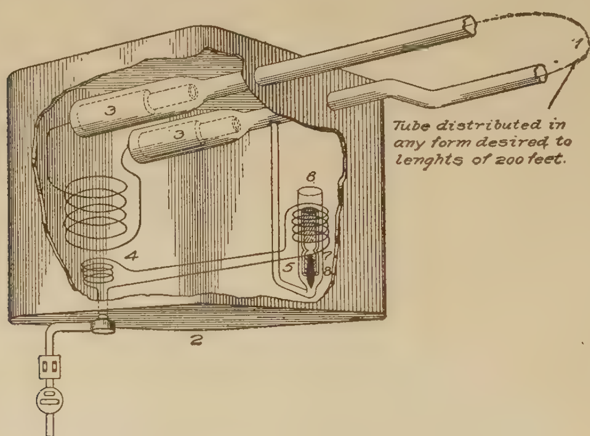


Fig. 33. Diagram Showing Essential Features of Moore Light. 1, Lighting Tube; 2, Transformer Case; 3, Lamp Terminals; 4, Transformer; 5–8, Regulators

to it when the tube is in operation. The tube gives the highest efficiency when nitrogen is employed, and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube, and carbon dioxide is employed when a white light is desired.

The only type of lamp which has been manufactured in commercial quantities is a short carbon-dioxide tube for accurate color matching; its light approaches natural daylight more closely than that of any other artificial illuminant. This tube consumes about 250 watts, and its construction is simpler than that of the larger sizes. Its application is in dye houses, for wool, silk, etc.

Neon Tube Light. *Characteristics and Advantages of Method.* Neon, a rare gas of which the atmosphere contains about one part in 66,000, can be obtained as a by-product of the manufacture of oxygen from the air and it may be used in connection with tube lighting in a manner similar to that in which nitrogen is used in the Moore lamp. When used in this manner it must be in a very pure state. Lamps have been manufactured for the use of neon, with the following general characteristics:

Tubes 6 meters long have a life comparable to that of incandescent lamp units, namely, 1000 hours or more.

The necessary potential is about one-third that required for a similar Moore tube—about 800 volts for a tube 6 meters long.

The neon tube gives about 200 candle-power per meter of length as against about 60 candle-power for a nitrogen tube.

An efficiency of 0.5 watts per candle is claimed for the neon tube.

Color of Light. The color of the light, unmodified, is too red for ordinary illumination. To improve this, correcting tubes containing mercury have been added to some lamps and, by the use of such correcting tubes, the color has been greatly improved, but the efficiency of the unit is reduced so that about 0.8 watt per candle-power is required for their operation.

Small tubes for display lighting have been manufactured but it is not at all likely that neon tubes, in their present state of development, will have any great commercial application, even though they have some very desirable characteristics.

CARBON-ARC LAMPS

ORDINARY OPEN- AND ENCLOSED-ARC TYPES

Principle of the Electric Arc. Suppose two carbon rods are connected in an electric circuit and the circuit is closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2000 cells and produced an arc between charcoal points 4 inches apart.

Nature of Arc. As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the

source of light for a large percentage of arc lamps, it will be well to study the nature of the arc. Fig. 34 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Action of Current on Carbons. Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the "crater" of the arc. This crater has a temperature of from 3000° to 3500° C., the temperature at which the carbon vaporizes, and it gives from 80 to 85 per cent of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater; and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden-yellow color. The arc proper does not furnish more than 5 per cent of the light emitted when pure carbon electrodes are used.

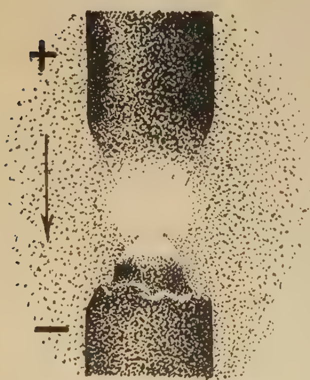


Fig. 34. Electric Arc between Carbon Terminals

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

Preparation of Carbons. Carbons are either molded or forced from a product known as "petroleum coke" or from similar materials, such as lampblack. The material is thoroughly dried by heating to a high temperature; then it is ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground, it is ready for molding. The powder is put in steel molds and heated until it takes the form of a paste, when the necessary pressure is applied to the molds. For the forced carbons, the powder is formed into cylinders which are placed in

machines that force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether molded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a different material seems to change the quality of light and, being more readily volatilized, keeps the arc from wandering.

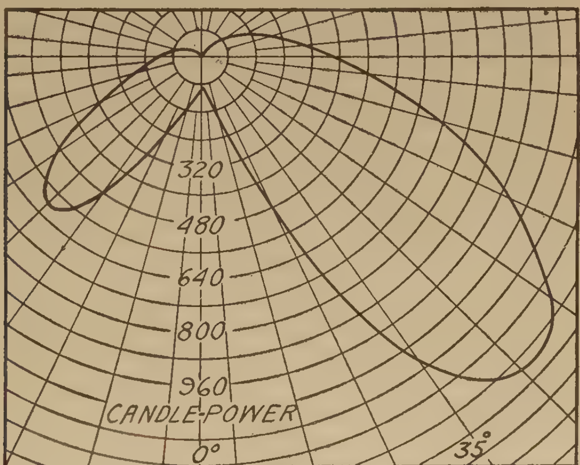


Fig. 35. Distribution Curve for D.C. Arc Lamp in Vertical Plane

Plating of carbons with copper is sometimes resorted to for molded forms for the purpose of increasing the conductivity and, by protecting the carbon near the arc, prolonging the life.

Distribution Curve. The light-distribution curve of a direct-current arc, taken in a vertical plane, is shown in Fig. 35. Here it is seen that the maximum amount of light is given off at an angle of about 50 degrees from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

If alternating current is used, the upper carbon becomes positive and negative alternately and there is no chance for a

crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light-distribution curve of an alternating-current arc is shown in Fig. 36. The lack of symmetry shown on Figs. 35 and 36 is due to the wandering of the arc.

In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons

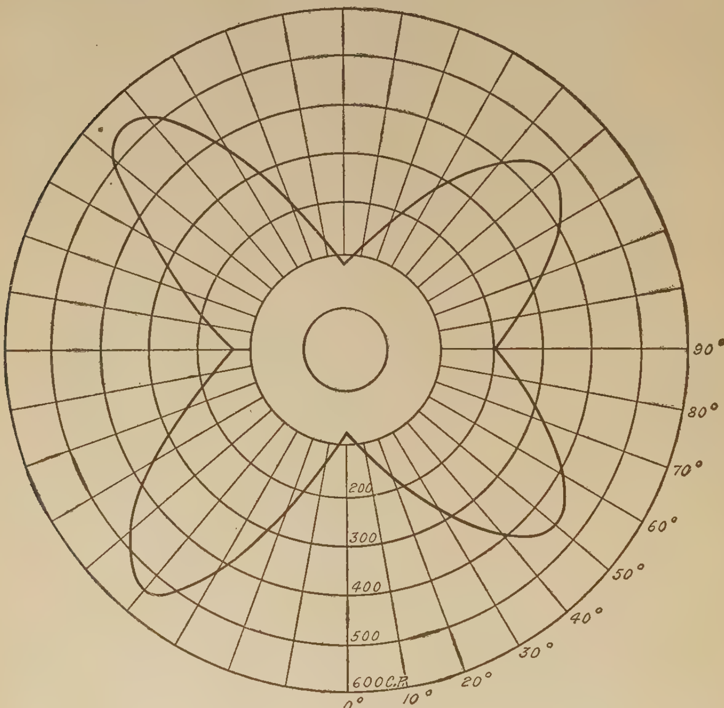


Fig. 36. Distribution Curve for A.C. Lamp in Vertical Plane

together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept at the proper distance apart by the operating mechanisms, which must perform the following functions:

(1) The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.

(2) They must be separated immediately afterward at the right distance to form a proper arc.

(3) The carbons must be fed to the arc as they are consumed.

(4) The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There is an endless number of such mechanisms—too many to try to describe them. They may be roughly divided into three classes: shunt, series, and differential mechanisms. In view of the decreasing importance of the arc light in illumination and because a description of these mechanisms is rather detailed, no further mention of them is made here.

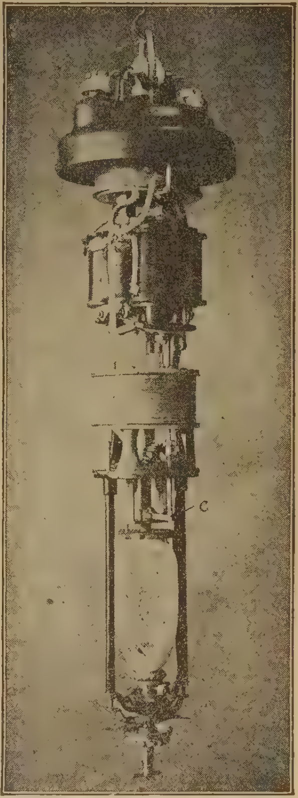


Fig. 37. Enclosed Arc Lamp Showing Carbon-Feed Mechanism

Classification. Arc lamps are constructed to operate on direct-current or alternating-current systems when connected in series or in multiple. They are also made in both the open and the enclosed forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly airtight. Fig. 37 is a good example of an enclosed arc.

Open Type. Open arcs for direct-current systems were the first to be used to any great extent. When used they are always connected in series and are run from some form of special arc machine, a description of which may be found in any book dealing with types of generators.

The principal advantage of the open arc was its high efficiency; with an energy consumption of less than 500 watts, the

lamp furnished a maximum intensity of about 1200 candle-power. The chief disadvantage of the open-arc lamp from the standpoint of street illumination was the poor light distribution. Most of the light was thrown down at an angle of about 45 degrees so that there was a very bright ring of light on the street surface near the lamp and that part of the street farther away was left in comparative darkness. Further, since the lower carbon was close to the upper, it cut off a large part of the light emitted from the crater and cast a dark shadow on the street immediately beneath the unit. The position of the shadow varied considerably, for the arc stream was not stationary, but wandered slowly about the circumference of the carbon. In many instances the inequality of the distribution of light about the lamp was exaggerated by the uneven burning of the carbons.

The recognized rating for the open-arc carbon lamp has always been 2000 candle-power in spite of the fact that even the maximum intensity seldom exceeded 1200 candle-power. The 2000-candle-power value appears in a great many of the old street-lighting contracts and has been the source of much litigation. The origin of the rating probably lay in the fact that the arc lamp gave a great deal more light than any lighting unit previously known and the photometers in existence at the time of its invention were inadequate for the purpose of measuring intensities so high.

The decisions of the courts of law passing upon this question have been to the effect that the 2000-candle-power rating merely described a particular type of lamp and had nothing to do with the actual intensity obtainable from it.

Each lamp requires in the neighborhood of 50 volts for its operation and, since the lamps are connected in series, the voltage of the system depends on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine but even this size of generator is not as efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed

TABLE VII

Data for Multiple Enclosed-Arc Lamps

Lamp	Volts	Equipment	Watts	Total Lumens	Lower Hemispherical C-p.
$3\frac{1}{4}$-ampere d.c.	220	A	715	160	215
5 -ampere d.c.	110	B	550	190	245
$6\frac{1}{2}$-ampere d.c.	110	B	715	275	360
6 -ampere a.c.	110	A	430	145	240
$7\frac{1}{2}$-ampere a.c.	110	A	500	195	325

Equipment A, opal inner globe and reflector, no outer globe.
Equipment B, opal inner, clear outer, no reflector.

daily for this type of lamp. The open-arc lamp is used but little at present.

Enclosed Type. Enclosed arcs for series systems are constructed much the same as the open lamp and are controlled by either shunt or differential mechanism. They require a voltage of from 68 to 75 at the arc and are usually constructed for from 5 to 6.8 amperes.

Constant-Potential Type. Constant-potential arcs must have some resistance or reactance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 37, one coil being located above and the other below the operating solenoids.

In enclosed arcs the carbons are not consumed as rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without trimming.

Table VII gives data as to the light generated by the more common types of multiple-enclosed arc. The candle-power of series lamps of the same amperage did not differ materially from these figures. In the case of the direct-current lamps, however, the wattage of the series type was 30 per cent less than for the multiple owing to the elimination of the resistance loss. The type of diffusing and reflecting equipment affects the light distribution to some extent. Curves for the types most used in street lighting are given in Fig. 38.

Flaming Arc. In the carbon arc, the arc proper gives out but a small percentage of the total amount of light emitted. In order

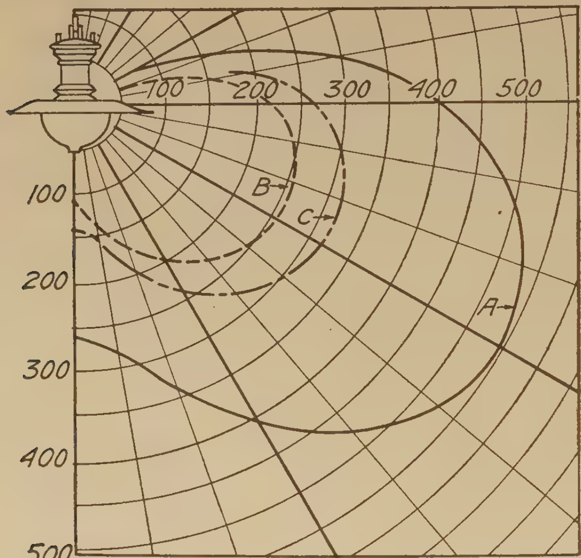


Fig. 38. Distribution Curves for Various Sizes of Lamps Equipped with Street Reflector, Light-Opal Inner and Clear Outer Globe. Curve *A* is for 6.6 Amperes D.C. Arc; Curve *B* for 6.6 Amperes A.C. Arc; and Curve *C* for 7.5 Amperes A.C. Arc

to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different from carbon. The result of these experiments has been to place upon the market the flaming-arc lamps and the luminous-arc lamps—lamps of high candle-power and good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being either impregnated with certain salts which add luminosity to the arc, or else they are fitted with cores which contain the required material;

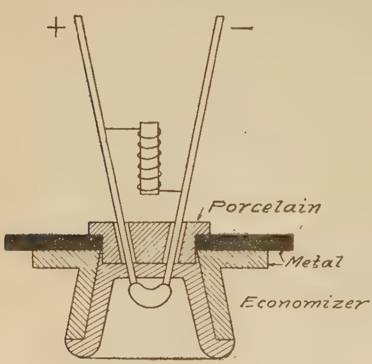


Fig. 39. Diagram of Bremer Flaming Arc

the other class covers lamps which do not employ carbon, the most notable example being the magnetite arc, which uses a copper segment as one electrode and a magnetite stick as the other electrode.

Bremer Type. The Bremer flaming-arc lamp was introduced commercially in 1899. The diagram shown in Fig. 39 illustrates the main features of this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping it from creeping up and injuring the economizer and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied

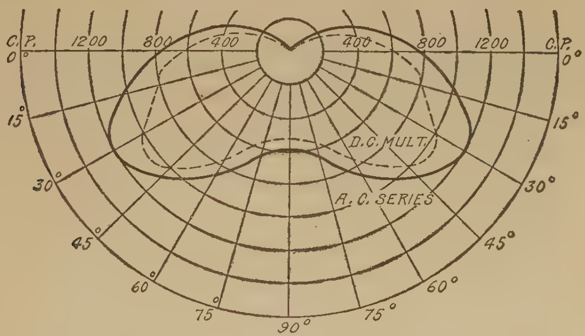


Fig. 40. Distribution Curves for Flaming-Arc Lamps; D.C. Multiple Lamp for 6.6 Amperes; A.C. Series Lamp for 10 Amperes

to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps differ greatly in their make-up. Some use impregnated carbons; others use carbons with a core containing the flaming materials; and metallic wires are added in some cases. The life of electrodes for flaming lamps depends upon their length and upon the type of lamp. For the open type

TABLE VIII

Data for the Flaming-Arc Lamps Compared in Fig. 40

	A.C. Series Lamp	D.C. Multiple Lamp
Terminal Volts	52	115
Terminal Watts	425	747.5
Arc Volts	46	70
Arc Watts	395	455
Amperes	10	6.5
Efficiency	93%	61%
Power Factor	81.6%	......
Mean Hemispherical C-p	1000	820
Mean Spherical C-p	655	500
Mean H. S. C-p per Watt	2.35	1.09
Mean Spherical C-p per Watt	1.54	.67

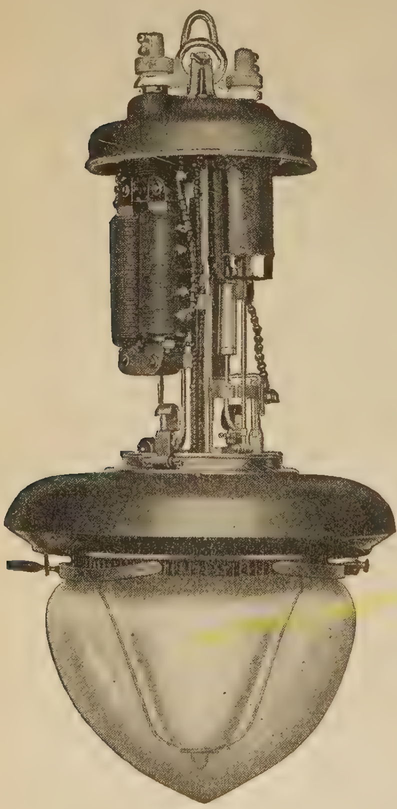


Fig. 41. Enclosed A.C. Series Flaming-Arc Lamp without Hood
Courtesy of General Electric Company, Schenectady, New York

lamp 12 hours, and for the enclosed type 100 hours, may be considered as representative.

Color of Arc. The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound and many of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced; while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. Fig. 40 gives a comparison between a 6.5-ampere direct-current multiple lamp and a 10-ampere alternating-current series unit illustrated in Fig. 41. Table VIII gives data relative to these two lamps of the enclosed type, both equipped with "white" carbons.

The installation of flaming-arc lamps today is practically confined to special fields, such as photo-engraving, moving-picture studios, fading tests of dyes and paints, etc., in which the actinic rays of the arc are particularly desired. On account of the tendency toward poor candle-power maintenance caused by the deposit of ash on the globe and because of the relative unsteadiness of the light the flaming-arc lamps have been largely superseded in general industrial and street lighting by the magnetite-arc and the Mazda lamps.

LUMINOUS-MAGNETITE OR METALLIC-FLAME ARC LAMPS

Such lamps were introduced as early as 1903. The type most commonly employed uses a copper disc as one electrode and

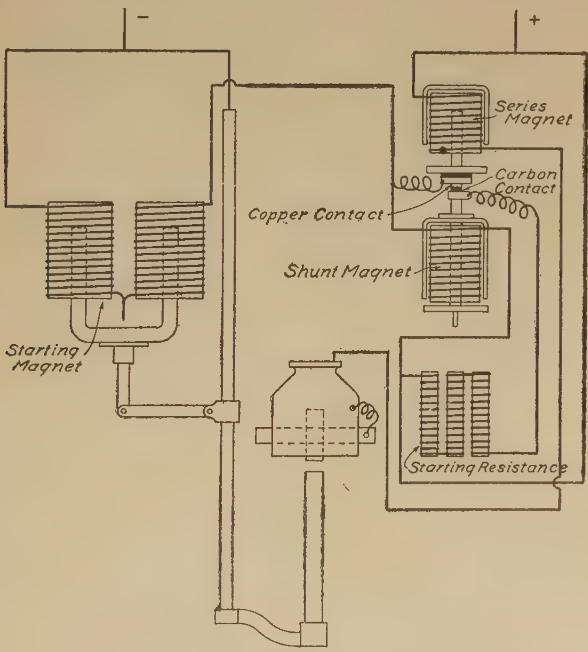


Fig. 42. Diagram of Connections for Luminous-Arc Lamp

a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet-steel tube—as the other electrode. This lamp gives a luminous arc of high efficiency and

TABLE IX

Data for Series-Burning Direct-Current Luminous-Arc Lamps

Lamp and Equipment	Volts	Watts	Equipment	Total Lumens	Lumens per Watt	Lower Hemispherical C-p.
4-ampere long-life	82.5	330	A	3220	9.7	271
(350 hours)	77.5	310	B	3190	10.3	311
	77.5	310	C	3320	10.7	479
	77.5	310	D	3260	19.5	450
4-ampere high-efficiency	82.5	330	A	4970	15.1	434
(150 hours)	77.5	310	B	5010	16.2	493
	77.5	310	C	5320	17.2	758
	77.5	310	D	5030	16.2	698
5-ampere long-life	80.5	403	A	5020	12.5	429
(230 hours)	77.5	388	B	5090	13.1	515
	77.5	388	C	5350	13.8	770
	77.5	388	D	5179	13.3	693
5-ampere high-efficiency	80.5	403	A	7640	19.0	654
(125 hours)	77.5	388	B	7260	18.7	737
	77.5	388	C	7660	19.7	1100
	77.5	388	D	7260	18.7	1817
6.6-ampere long-life	80.5	532	A	9120	17.1	784
(120 hours)	77.5	510	B	8800	17.3	885
	77.5	510	C	9300	18.3	1297
	77.5	510	D	8960	17.6	1186

as the magnetite electrode is not consumed rapidly, magnetite lamps do not require frequent trimming. The life of the magnetite electrode, as at present manufactured, is from 100 to 350 hours. A diagram of the connections of this lamp, as manufactured by the General Electric Company, is shown in Fig. 42. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor.

Direct current must be used with this lamp, and is usually supplied from mercury-arc rectifiers, since practically all of the magnetite lamps built are on the series type. The light from this lamp is white in color, its candle-power maintenance is good, and it has met with much favor in both utilitarian and orna-

mental street lighting. A greater variety of standard reflecting and diffusing equipment has been developed for the luminous lamps than for any other type of arc. Fig. 43 shows the distribution curves for the more usual of these accessories in connection

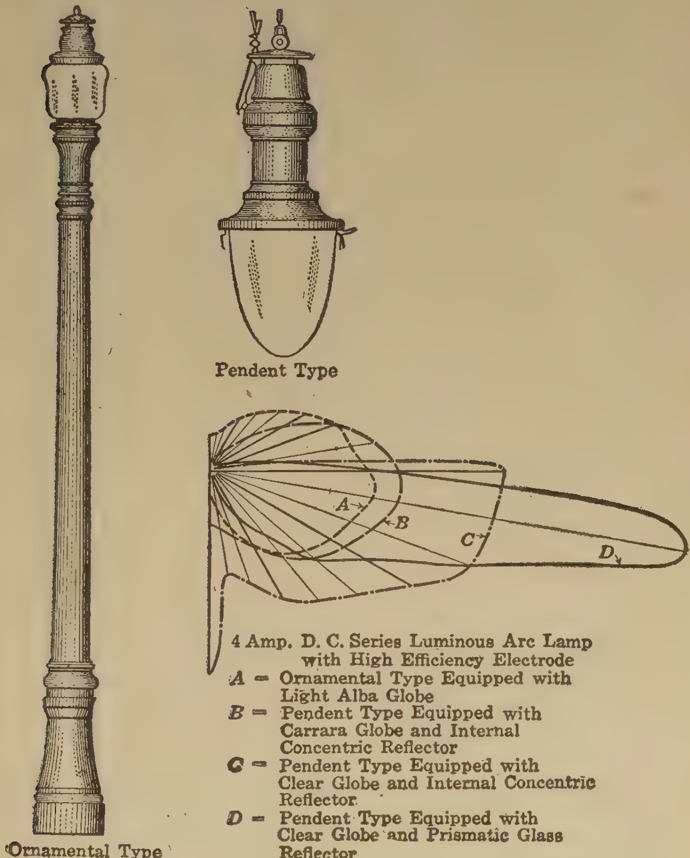


Fig. 43. Candle-Power Distribution Obtained with Different Equipments, 4-Ampere Luminous-Arc Lamps

with a 4-ampere lamp equipped with long-life electrodes. Table IX gives candle-power data for the standard amperages and electrodes. It will be noted that the type of electrode, that is, whether designed for high efficiency or for long life, greatly affects the candle-power output of the lamps.

INTERIOR OF ASBURY M. E. CHURCH, ROCHESTER, NEW YORK, SHOWING LIGHTING FIXTURES
Courtesy of "Electrical Reveiw," Chicago, Illinois

ELECTRIC LIGHTING

PART II

REFLECTORS AND ENCLOSING GLASSWARE

The light from a bare lamp is distributed in a manner such that under most conditions it cannot be employed effectively without the use of reflectors or enclosing glassware. These accessories should not only redirect light, which would otherwise be ineffective, into useful angles, but should serve the additional purposes of modifying the brilliancy of the source and diffusing the light to produce a soft and pleasing illumination.

Systems of Interior Lighting. Three systems of interior lighting are commonly employed. They have been referred to as *direct, indirect,* and *semi-indirect.* In the so-called direct-lighting system, the unit distributes the light downward into the room; in the indirect system, all the light is thrown upon the ceiling and thence reflected into the room; in the semi-indirect system, a greater part of the light is thrown upon the ceiling but some of it passes through the diffusing glassware directly into the room. In the units for these systems, various reflecting surfaces and transmitting media are used, and a knowledge of the action of such surfaces and media in the utilization of light is necessary to their proper selection.

Control of Light. A ray of light will travel along a straight line indefinitely unless interfered with by some object or medium. The effect of such interruption may be absorption by the medium through which the light passes or by the object which it strikes. This is noticed when a beam of light passes through smoky atmosphere, through smoked glass, or meets a black opaque body. In these cases, a part or practically all of the light loses its identity and is converted into heat. A second phenomenon is termed refraction. Refraction is a bending of the ray of light due to its passing from one medium to another of greater or less density, as, for example, from air to water or from air

to glass. A very common instance of refraction is the apparent bending of a fishline at the point where it enters the water; of course the line is straight, but the light rays coming from that part of the line which is under the water are refracted when they pass from water into air. Another way in which a light ray may be diverted from its course is by reflection, which is the throwing back or redirection of the ray by a surface. A fourth is diffusion, which is the breaking up of the beam and spreading of its rays in all directions by the medium through which it passes or by the surface upon which it falls. By controlling these four factors—absorption, refraction, reflection, and diffusion—we are able to make the light from any source do very largely as we desire.

Polished-Metal and Mirrored-Glass Reflectors. The simplest form of reflection is that which takes place when a ray of light strikes a polished-metal surface. As indicated at *A*, Fig. 44, a ray of light having a direction *sa* on striking a polished-metal surface is reflected off in the direction *ab*, so that the angle *y*, made with a perpendicular to the surface by the reflected ray (angle of reflection), is equal to the angle *x*, made by the incident ray (angle of incidence). Practically no light is reflected in other directions. This is called regular reflection. It will be seen, therefore, that it is possible to redirect light in any desired direction by means of a properly placed reflecting surface. When we consider that the schoolboy by means of a pocket mirror or piece of polished metal can take the beam of sunlight that comes in at the window and redirect it with remarkable accuracy to any place in the room, the general principle involved is seen to be simple. While all polished-metal surfaces reflect light in the manner described, they do not reflect it in like amounts. For instance, if two beams of 100 lumens each fall respectively on a polished-silver surface and on a polished-aluminum surface, the silver will reflect approximately 88 lumens, and the aluminum about 62 lumens. In other words, the silver surface will absorb only 12 per cent of the light, while the aluminum surface will absorb about 38 per cent. All the light falling upon an opaque surface is either reflected or absorbed by that surface.

Similiar to the reflection characteristics of polished metal are those of mirrored glass. At *B*, Fig. 44, is shown the path of a ray of light striking the surface of a commercial type of mirror with silvering on the back of the glass. A small part of the light is reflected by the polished surface of the glass and does not pass through to the silvered backing; the remainder passes back through the glass and after leaving the glass travels in a direction parallel to the ray reflected from the glass surface. The fact that most of the light has to pass through the glass both to and from the reflecting surface makes the silvered mirror, from a laboratory standpoint, a less efficient reflecting surface than the polished silver itself. For instance, if 100 lumens strike a mirror the reflections and absorptions are of the following order

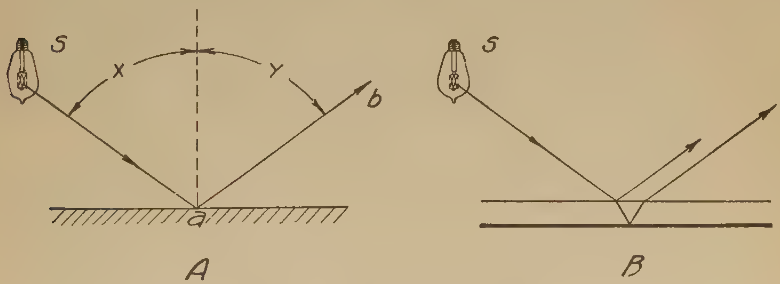


Fig. 44. Reflections from *A*, Polished Surface; *B*, Mirrored Surface

of magnitude: 10 are reflected by the exposed surface of the glass, 10 are lost by being absorbed by the silvered surface, and 5 are absorbed by the glass, leaving a total of about 75 lumens which are reflected by the silvered surface; the loss in the glass depends, of course, on the quality of the glass. The deterioration of a polished-metal reflecting surface in service is, however, a factor which often more than offsets its higher initial efficiency.

To obtain a desired distribution from a polished-metal or a mirrored surface, it is necessary that the contour of the reflector be such that at as many points as possible the reflecting surface be at such an angle with the incident ray that the reflected ray will be in the desired direction of light. For example, where parallel rays of light are desired, as in the case of automobile headlights, the reflector will have to be a parabola or some modification of

it, Fig. 45. A hemispherical reflector, on the other hand, placed behind the lamp, with its center coinciding with the light source, will not concentrate the light at all, but will merely double the candle-power at each angle in the other hemisphere, since each ray that strikes the reflector is reflected back along the same line, through the source. Mirrored reflectors have a disadvantage in that they throw brilliant images of the filament, or striations, on the surfaces illuminated. In practice, these striations are often eliminated by corrugating the reflector or frosting the lamp, with, however, some loss in the control of the light.

Since polished-metal and mirrored surfaces follow definitely the law of regular reflection, these surfaces are used in reflectors

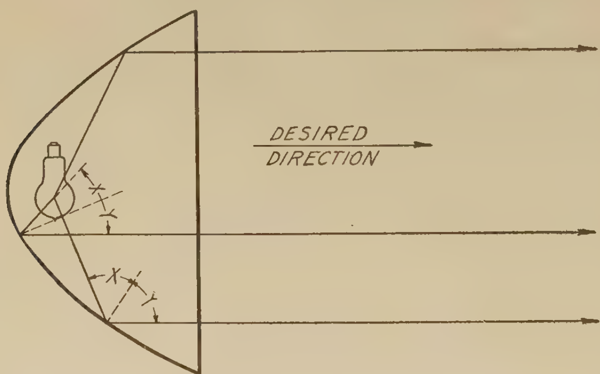


Fig. 45. Accurate Light Control May Be Obtained from Polished-Metal or Mirrored Surfaces

where the aim is to obtain definite and accurate control of the direction of the light. Arc and incandescent searchlights, automobile headlights, and the flood lighting units are the most familiar applications of such reflectors for accurate light control. Mirrored glass is also widely used for both direct- and indirect-lighting units, Figs. 46 and 47.

Dull-Finish or Semi-Mat Reflectors. A dull-finish or semi-mat surface can be considered as one which has innumerable small reflecting surfaces making numberless slight angles with the general contour. A surface coated with aluminum paint affords a good example. When a shaft of light strikes such a surface, the rays are reflected at slightly different angles, but all

Mirrored Glass

Zone	Lumens	% Total Clear Lamp
0°-60°	1750	60
0°-90°	1985	68

Clear Lamp

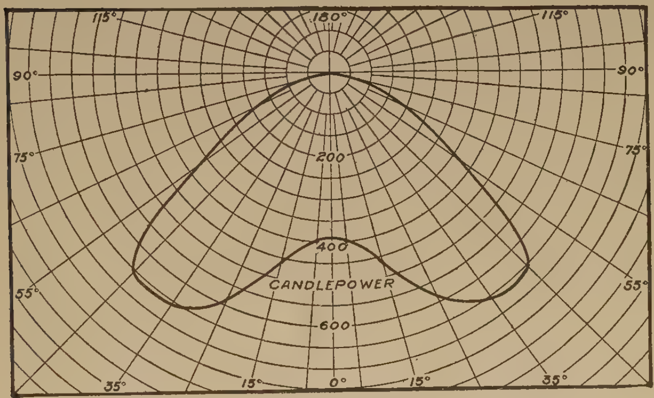


Fig. 46. Candle-Power Distribution Curve for Clear Lamp with Mirrored-Glass Reflector

Indirect

Zone	Lumens	% Total Clear Lamp
90°-180°	2340	80
120°-180°	1605	55
0°-180°	2340	80

Clear Lamp

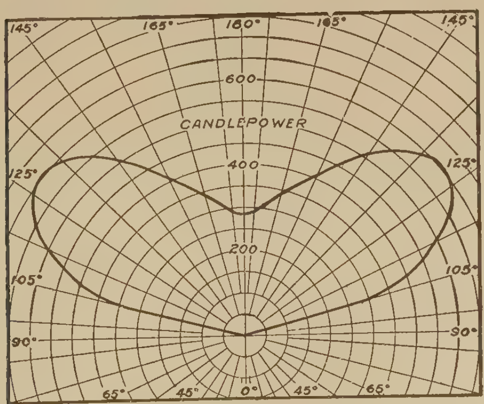


Fig. 47. Candle-Power Distribution Curve for Clear Lamp with Indirect Reflector

in the same general direction, as shown in *A*, Fig. 48. This is known as spread reflection. The spread of the reflected beam indicated by the angle between lines *ac* and *ad* is dependent upon the degree of smoothness of the surface, the smoother the surface the narrower the angle. When the reflecting surface is viewed along the line *ba*, no distinct image of the light source is visible, but only a bright spot of light.

The reflection characteristics of dull-finish or semi-mat surface reflectors are similar to those of reflectors having polished surfaces except that in the case of the former the light is redirected with less accuracy. Dull-finish reflectors of deep bowl shape, for example, unless carefully designed, are likely to lose some of their efficiency owing to cross-reflection from one side to the other and consequent absorption of the light. This is

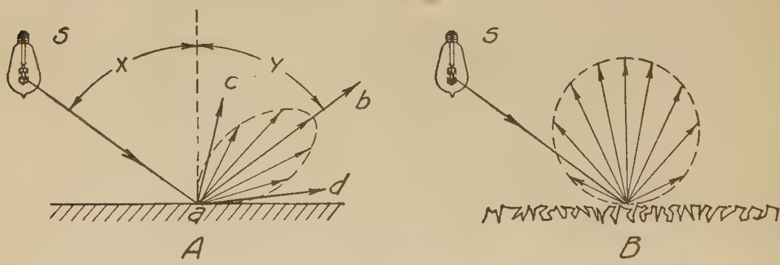


Fig. 48. Reflections from Smooth and Rough Surfaces. *A*, Semi-Mat Surface; *B*, Reflection from Rough Mat Surface

not so likely to occur with a polished reflector of the same shape. The aluminumized-steel reflector is the only commercial semi-mat reflector which has been generally used.

Rough Mat-Surface Reflectors. If a mat surface is so rough that it has absolutely no sheen, as, for example, the surface of blotting paper, beams of light on falling into the minute pockets are reflected back and forth, so that when finally they come out they travel severally in all directions, as indicated in *B*, Fig. 48. The result is that the whole surface appears as bright from one direction as from another, that is, just the same as it would if it were luminous from being heated to incandescence. In other words, the candle-power per square inch of apparent area is uniform. It is a maximum in a direction per-

pendicular to the surface, for the surface has the greatest apparent area when viewed from this direction. When the measurement is made from any other direction the apparent area is less, and since the candle-power per square inch of apparent area is constant, the candle-power is less. White blotting paper is one of the best examples of the diffusing type of reflecting surface; a good sample will reflect about 80 per cent of the light which strikes it.

Since light which falls upon a rough surface is reflected in all directions, it follows that the shape of reflectors using such a surface has little effect on the resulting distribution of light. In Fig. 49, *s* represents a light source at the mouth of a rough-surface reflector *aaa*. The light distribution is the same when the reflector has the cross-section *aaa*, *bbb*, or *ccc*, for when the reflector is viewed from below, it simply appears as a white disk. However, if a contour such as *bbb* or *ccc* is used rather than *aaa*, there will result a needless absorption of light due to cross-reflection of light between the inside surfaces, and the light from *s* would, therefore, be utilized to better advantage with the shape *aaa*.

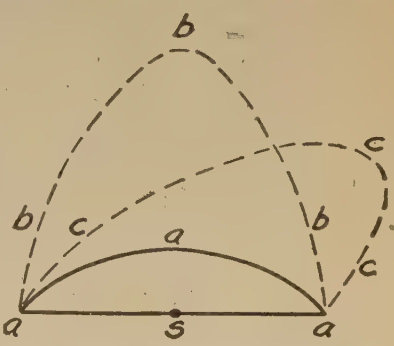


Fig. 49. Shape of Rough Surface Reflector Has Relatively Little Effect on Distribution

Reflectors having a rough reflecting surface are difficult to keep clean and are therefore seldom used, since opal glass and porcelain enamel offer the same advantages without this disadvantage.

Prismatic Glassware. Prismatic glassware, as it is usually employed in lighting units, is made up of many small prisms which compose the entire body of the reflector. The principle involved is that of total reflection. At *A*, Fig. 50, is shown the path of a single light ray; the angles of the prism can be made such that when the light ray passes into it and strikes the back surface *bc* it is reflected to the surface *ac* and out again as shown. It will be observed that, for all practical purposes, this

reflection is the same as would be obtained from a polished-metal or mirrored surface; that is, each prism is the equivalent of a narrow strip of mirror. By tilting this strip longitudinally, the direction of the reflected beam can be accurately controlled, and by giving it the proper curvature the desired distribution of all the light falling on it can be obtained. The tops of the prisms are usually rounded slightly, which permits the transmission of a small percentage of the light and thus improves the appearance of the reflector. Prismatic glassware of proper design does not produce striations.

Dust on the exterior of a prismatic reflector reduces the light in the upper direction only, but moisture and moist dirt in optical contact with the exterior surface affect the reflecting

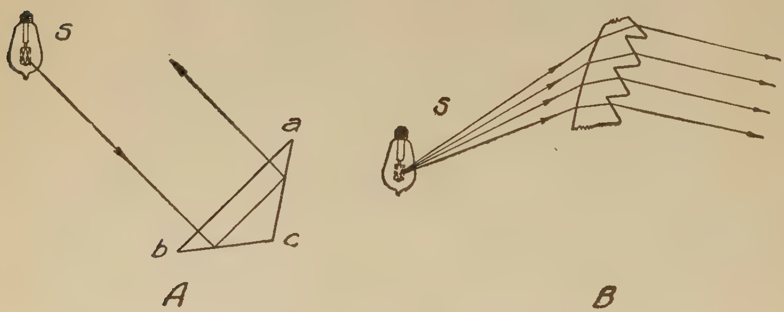


Fig. 50. Reflection and Refraction. *A*, Reflection by Prism; *B*, Refraction by Prisms

power of the prisms and reduce the light output both upward and downward.

A typical prismatic-glass reflector recommended for industrial lighting is shown in Fig. 51. So-called velvet-finish prismatic-glass reflectors, Fig. 52, are also available. These reflectors give a distribution similar to that of a semi-mat or dull-finish reflector, for, as will be discussed in a subsequent paragraph, the etching on the inside surface of the reflector gives spread characteristics to the reflected light.

Prismatic glassware is also used for refracting or changing the direction of light rays passing through, as in a lighthouse lens. The prisms used in refractors are of different shape from those used in reflectors. The paths of light rays through four

prisms of a refractor are indicated at *B*, Fig. 50. Refractors are used with incandescent or arc lamps where a very broad distribution of light is desirable, as in the case of street lights. (See Figs. 105–106.)

Since with both prismatic reflectors and refractors the light is reflected by or passed through clear glass only, the absorption is low, and the efficiency of such glassware is of the highest order. With prismatic glass, as with mirrored reflectors and all

Prismatic Industrial

Clear Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1840	63
0°-90°	2130	73
90°-180°	525	18
120°-180°	292	10
0°-180°	2660	91

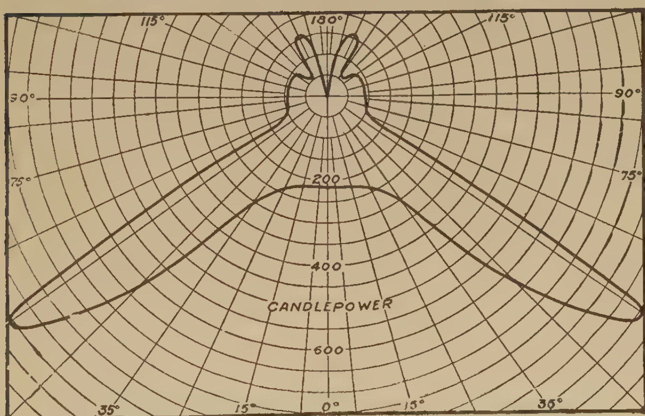
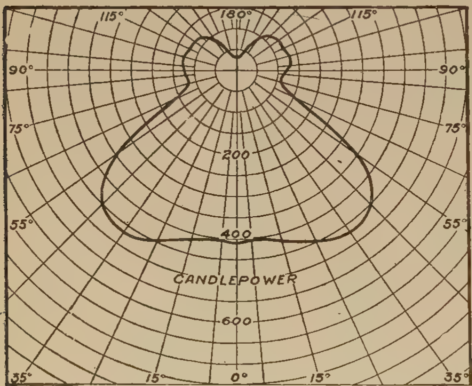


Fig. 51. Candle-Power Distribution Curve of Clear Lamp with Prismatic Industrial Reflector

other types that afford an accurate control of light, it is especially necessary that the light center of the lamps shall be in the correct position with respect to the reflector; in other words, that the proper size of lamp, with the proper holder, shall be used in each case, or the desired distribution will not be obtained.

Opal Glassware. Opal glass finds considerable application in illumination practice both as a reflecting and a transmitting medium. In general, there are two types of opal glass, classed as dense and light. The properties of opal glass can be most

readily understood if we regard it as common glass in which fine white particles are, so to speak, held in suspension. When a ray of light strikes this surface, part of the light is reflected



Prismatic Intensive

Bowl Frosted Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1315	45
0°-90°	1720	59
90°-180°	672	23
0°-180°	2400	82

Fig. 52. Candle-Power Distribution Curve of Bowl-Frosted Lamp with Prismatic Intensive Reflector

directly, as in the case of a polished-metal surface. The remainder of the light travels through the glass in straight lines until it strikes the white particles, or any minute air bubbles which

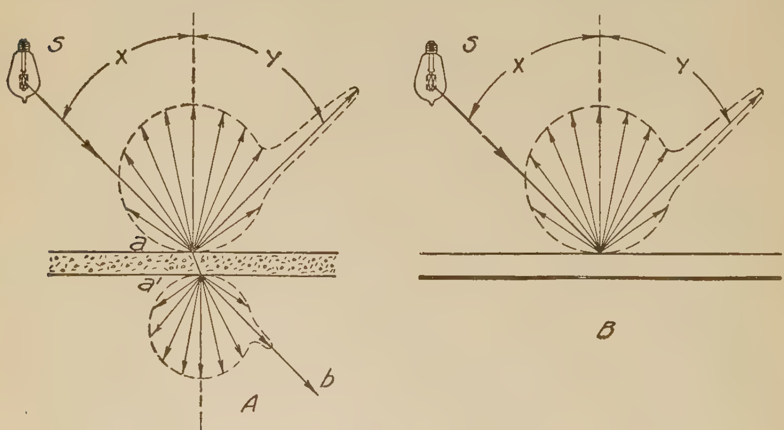


Fig. 53. Diagram Showing Reflection and Transmission. *A*, Reflection and Transmission of Opal Glass; *B*, Reflection from Porcelain-Enameled Steel

may be present, whence it is dispersed in all directions, some of it being thrown back and reflected as shown at *A*, in Fig. 53, and the remainder being transmitted through and out in all

directions. If by chance a ray of light passes through the glass and fails to strike any of the white particles, it goes out in a line parallel to the one along which it entered. Thus, if a lamp were enclosed in a ball of opal glass, through which on the average, say, one ray in a hundred could pass without striking any of the white particles, the filament outline would be visible. In the case of *A*, Fig. 53, this would be in the direction *ba′*.

The effectiveness of opal glass in redirecting light depends upon the number of white particles and their density in the glass. An opal glass which permits only about 10 per cent of the light striking it to pass through is classed as very dense; light opals may allow as much as 60 per cent to be transmitted. A totally enclosing opal-glass ball may, however, have an over-all output as high as 80 per cent; for, while only 60 per cent of the light coming directly from the lamp to a point on the surface may be transmitted, sufficient reflected light may also come to this point from the illuminated interior of the ball to bring the total transmission of the ball up to 80 per cent.

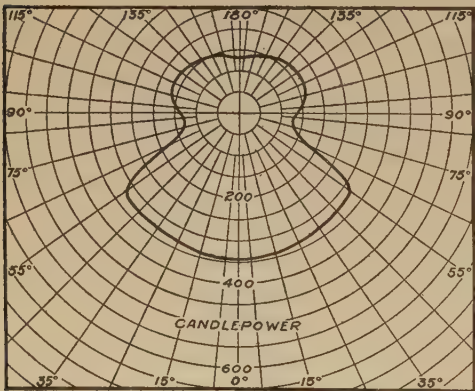
For a typical test piece of glass of the common type, with 40 per cent transmission, about 10 per cent of the total is directly reflected, 10 per cent is absorbed by the glass, and the other 40 per cent is reflected in all directions.

Dense opal glass need not be thick. A thin coating of a dense mixture may be "flashed" on a body work of clear glass of ordinary thickness to produce what is known as flashed opal. Tests have shown that such glass usually absorbs less light than ordinary opal glass of equal diffusing power; hence flashed opal is particularly adapted to use in enclosing units, where the lightest density which will hide the filament is desirable and where greater density results in unnecessary absorption.

A more recent development in lighting glassware is the application of a fired, white enamel coating to crystal glassware. The characteristics of this enamel coating, from the illumination standpoint, are identical with those of opal glass, and the fact that any portion of a unit may be left clear while the rest is diffusing, offers many new possibilities in effective control of light.

Two important advantages make opal glass a very desirable reflector material: (1) its smooth surface minimizes the collection

of dust and permits easy cleaning; (2) the glass transmits a portion of the light, which renders the reflector luminous and



Light Density Opal

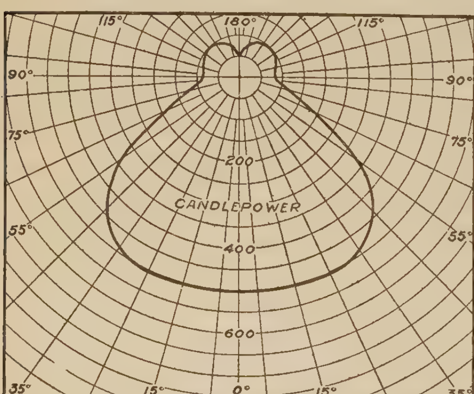
Bowl Frosted Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1020	35
0°-90°	1490	51
90°-180°	995	34
0°-180°	248	85

Fig. 54. Candle-Power Distribution Curve of Bowl-Frosted Lamp with Light-Density Opal Reflector

thereby adds materially to its appearance. These two advantages are largely responsible for the wide use of opal glass for reflectors and reflecting equipment.

Opal glass is used for open reflectors, Figs. 54 and 55; for semi-enclosing units, Fig. 56; for balls, Figs. 57 and 58; for stalactites



Dense Opal

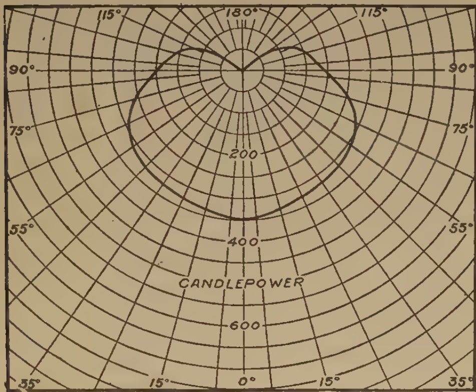
Bowl Frosted Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1345	46
0°-90°	1750	60
90°-180°	584	20
0°-180°	2340	80

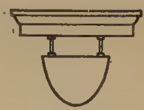
Fig. 55. Candle-Power Distribution Curve of Bowl Frosted Lamp with Dense Opal Reflector

and other forms of enclosing diffusers and for semi-indirect units, Figs. 59 and 60. Owing to the fact that the reflected light is

diffused, the contour of a reflector is a less important factor than it is in the case of mirrored-glass or prismatic reflectors, and the



Shallow Reflector

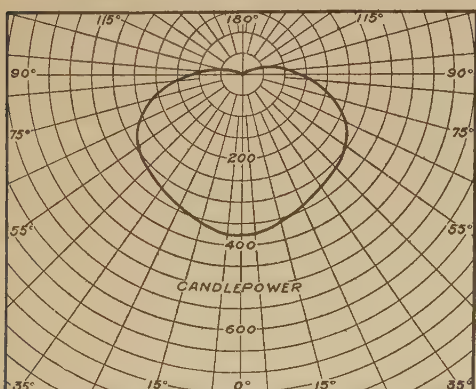


Diffusing Bowl

Zone	Lumens	% Total Clear Lamp
0°-60°	995	34
0°-90°	1750	60
90°-180°	585	20
0°-180°	2330	80

Fig. 56. Candle-Power Distribution Curve of Clear Lamp with Diffusing Bowl and Shallow Reflector

design is determined largely by artistic considerations. Lighting units with opal enclosing glassware are popular for use with high-power incandescent lamps because of the good diffusion obtained for a direct-lighting fixture and because of the variety of attractive designs available. The light distribution of an



Diffusing Globe

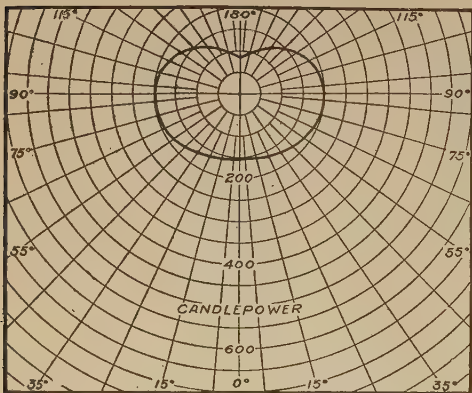
With Reflector

Zone	Lumens	% Total Clear Lamp
0°-60°	1020	35
0°-90°	1695	58
90°-180°	175	6
0°-180°	1870	64

Fig. 57. Candle-Power Distribution Curve of Clear Lamp with Diffusing Globe and Reflector

enclosing globe made entirely of opal glass is almost independent of its shape.

One of the main advantages of semi-indirect lighting is that the use of dense opal glass makes it possible to reduce the



Diffusing Globe

Light Opal

Zone	Lumens	% Total Clear Lamp
0°-60°	555	19
0°-90°	1168	40
90°-180°	1020	35
120°-180°	438	15
0°-180°	2190	75

Fig. 58. Candle-Power Distribution Curve of Clear Lamp with Light Opal Diffusing Globe

Semi-Indirect

Light Opal

Zone	Lumens	% Total Clear Lamp
0°-60°	380	13
0°-90°	730	25
90°-180°	1750	60
120°-180°	1370	47
0°-180°	2480	85

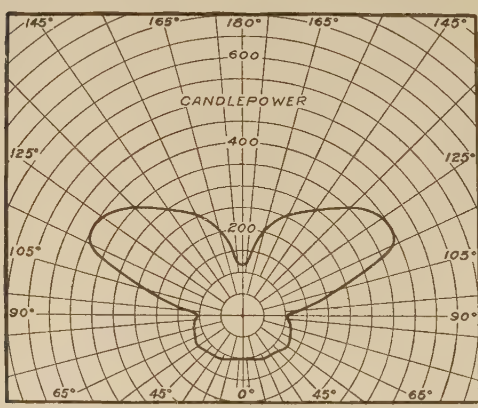


Fig. 59. Candle-Power Distribution Curve of Clear Lamp with Light Opal Semi-Indirect Bowl

brightness of the unit to a level comparable with the brightness of adjacent surfaces in the room. Units for offices, schoolrooms,

and the like should be of sufficiently dense glass. For example, the unit whose curve is shown in Fig. 60 is better than Fig. 59.

Frosted-Glass Reflectors and Globes. Frosted-glass transmission characteristics may be likened to the reflection characteristics of a semi-mat surface. Fig. 61 shows the direction of a beam of light striking glass, the upper surface of which is smooth and the lower surface sand-blasted or roughed with acid etching. Some of the light is, of course, reflected from the glass as is shown in the figure, but most of it goes through the glass; and

Semi-Indirect

Dense Opal

Zone	Lumens	% Total Clear Lamp
0°-60°	175	6
0°-90°	292	10
90°-180°	2045	70
120°-180°	1750	60
0°-180°	2340	80

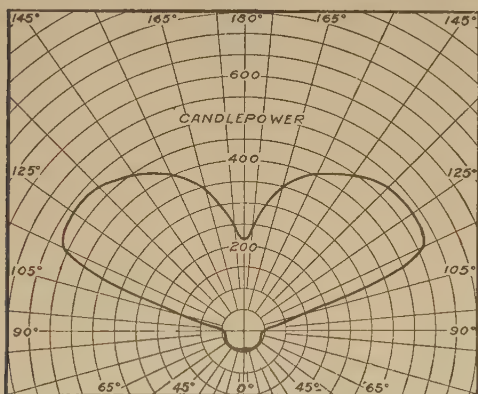


Fig. 60. Candle-Power Distribution Curve of Clear Lamp with Dense Opal Semi-Indirect Bowl

as the individual rays strike the rough surface they are partially dispersed. When the eye looks in the direction *ba*, only a bright spot is visible. A familiar illustration is the frosted Mazda C lamp, in which a central bright spot showing the location of the filament, but no distinct outline, is visible.

Etched glass should be used rather to give a spread transmission of light than to provide a good reflector. It is of little value except for enclosing units. Unless a frosted-glass surface is of a very fine texture, it accumulates dirt rapidly and is

difficult to clean. A recent tendency in illuminating engineering has been to make use of stippled or pebbled glass which has the diffusing characteristics of sand-blasted glass without the same roughness or difficulty in cleaning (Fig. 105). Glasses of this character are especially valuable where it is desired to transmit light without greatly changing its direction.

Color=Correcting Glass. As has been stated in an earlier chapter, the light from all incandescent lamps contains an excess of red and yellow rays when compared with average natural daylight. For many uses in which a source of daylight character is found desirable, the blue bulb, or Mazda C-2 lamp as it is called, will be satisfactory; it is about the equivalent of afternoon sunlight. Where extremely accurate color matching is essential, properly designed color-screen plates may be employed, which, when used in connection with a clear-bulb lamp, give an accurate duplication of northern-sky light. The light from such units is of constant quality and is in this respect superior to natural light, which varies from day to day. In correcting color to northern-sky light, however, the necessary absorption of the excess of warm-toned light rays amounts to nearly 85 per cent of the total light produced; consequently such units cannot be recommended for the general illumination of large interiors, being adapted for local lighting only.

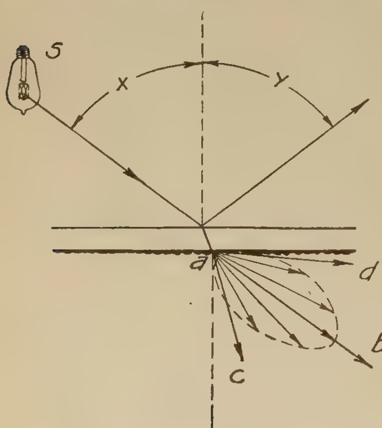


Fig. 61. Reflection and Transmission by Etched Glass

Many efforts have been made to incorporate color-correcting qualities in the opal glass of an enclosing globe. In nearly every case, however, it has been found that such opal glasses have a selective absorption for certain of the spectrum colors, and are in fact less to be relied upon in color discrimination than the direct light from a *clear-bulb* lamp. On the other hand, some glasses of this character have been developed which have a very pleasing white appearance and may well be used in many locations

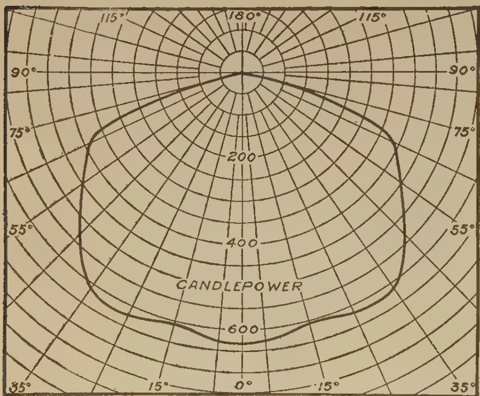
where accurate color discrimination is not necessary but where a daylight *effect* is desirable.

Porcelain-Enameled Reflectors. The familiar white-enameled metal reflector has a surface which, so far as its optical characteristics are concerned, can be considered as a plate of opal glass in optical contact with a steel backing. This opal must be very dense so that as little light as possible will pass through, for all the light that penetrates to the steel backing is absorbed, and therefore wasted. Enamels vary considerably in efficiency and if of two reflectors one appears gray in comparison with the other, it is sure to be considerably lower in efficiency. At *B*, Fig. 53, is shown the characteristic distribution of a porcelain-enameled surface on steel.

The durability of a porcelain-enameled steel surface, even under unfavorable atmospheric conditions, its moderate cost, its smooth surface—easy to clean—have made it the most generally employed for industrial and outdoor work. The reflection factor of porcelain enamel of good quality ranges from 65 to 70 per cent. While this value is not high, it is maintained permanently. Since some porcelain enamel is inferior from the standpoint of the reflection factor, care should be exercised in the selection of such reflectors. About five-sixths of the light returned from the enamel is reflected diffusely, as from a depolished or mat surface, and its distribution is therefore independent of the contour of a given reflector. The degree of control which can be exercised over the distribution of light is therefore limited, but is sufficient for most factory lighting requirements. In the design of a porcelain-enameled reflector, the angle at which the direct light from the lamp is cut off by the reflector and the area of the surface are the two characteristics of most importance.

The commonly employed types of porcelain-enameled reflectors are illustrated in Figs. 62 to 69. One of the earliest was the flat cone, Fig. 68. Today its application is limited to exterior lighting. For the illumination of interiors, this unit is never to be recommended, since a higher intensity of illumination of better quality can be obtained with other types. The edge of the reflector is at or above the center of the light source; hence not more than one-half of the light is intercepted, and the efficiency

of the unit in directing light to the work is of necessity low. Much of the light is emitted at or near the horizontal, and, striking high on the walls of the room, is to a large extent wasted.



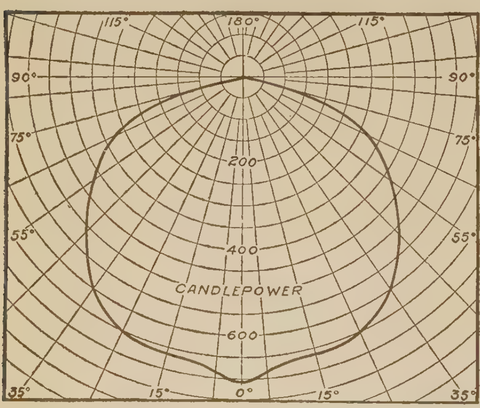
Porcelain-Enameled
RLM Dome

Clear Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1695	58
0°-90°	2220	76

Fig. 62. Candle-Power Distribution Curve of Clear Lamp with Porcelain-Enameled RLM Dome

With incandescent units no shielding of the bright filament of the lamp is afforded, hence the glare will be pronounced except where the units are used in very high bays, and here much of the



Porcelain-Enameled
RLM Dome

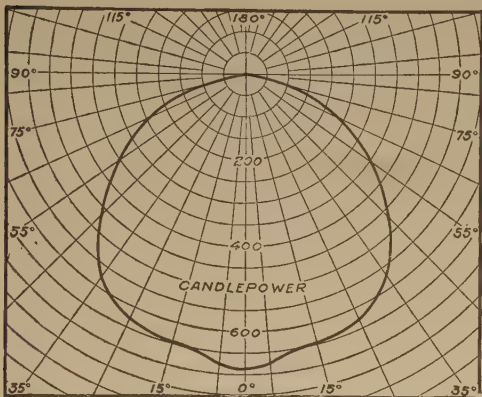
Bowl Frosted Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1695	58
0°-90°	2130	73

Fig. 63. Candle-Power Distribution Curve of Bowl Frosted Lamp with Porcelain-Enameled RLM Dome

light is wasted. Where lamps are suspended lower, even those with frosted bulbs will be glaring. The proportion of light received from the reflector is insufficient to soften shadows appreciably.

The deep, or bowl, reflector illustrated in Fig. 65 has been largely employed to give maximum shielding of the lamp filament. The mistake is frequently made of assuming that since this



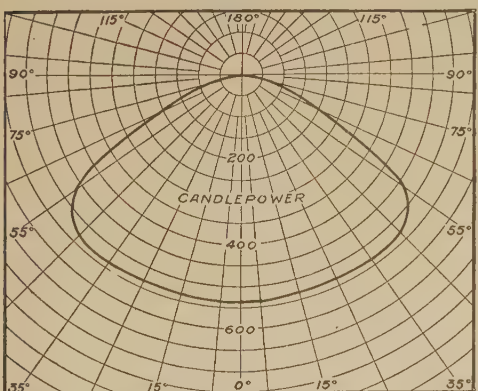
Porcelain-Enameled RLM Dome

Opal Cap

Zone	Lumens	% Total Clear Lamp
0°-60°	1548	53
0°-90°	1928	66

Fig. 64. Candle-Power Distribution Curve of Clear Lamp with Opal Cap and Porcelain-Enameled RLM Dome

reflector intercepts more light than other types, it is the most efficient in redirecting the light to the work. On the contrary, the output of typical bowl reflectors is only 65 per cent. The



Porcelain-Enameled Bowl

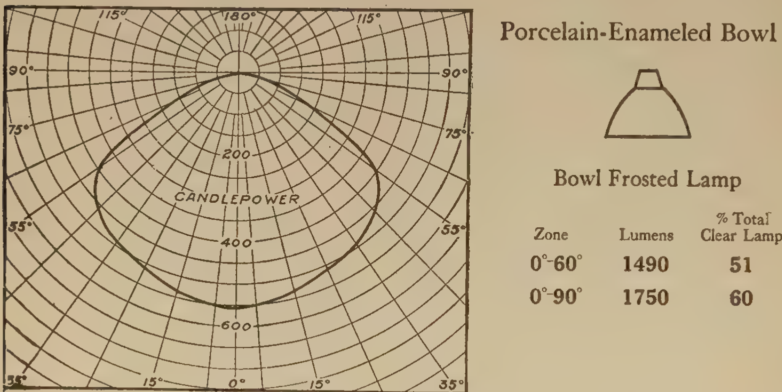
Clear Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1605	55
0°-90°	1900	65

Fig. 65. Candle-Power Distribution Curve of Clear Lamp with Porcelain-Enameled Bowl

candle-power below the unit is at no angle greatly different than for the dome, because of the losses resulting from cross-reflection in the reflector, and at the higher angles the intensity is con-

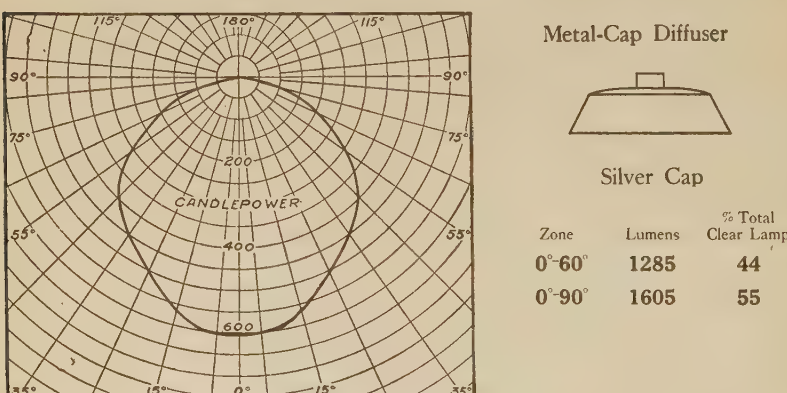
siderably reduced. Vertical and oblique surfaces above the general level of the work are frequently inadequately lighted with such units, and a room with dark surfaces is likely to appear



Zone	Lumens	% Total Clear Lamp
0°-60°	1490	51
0°-90°	1750	60

Fig. 66. Candle-Power Distribution Curve of Bowl Frosted Lamp with Porcelain-Enameled Bowl

dingy. While the deep reflector does shield the eye from the direct glare of the filament, it does not in any way modify the brightness of the filament images reflected from polished surfaces.



Zone	Lumens	% Total Clear Lamp
0°-60°	1285	44
0°-90°	1605	55

Fig. 67. Candle-Power Distribution Curve of Clear Lamp with Silver-Cap Diffuser

Furthermore, the surface from which the light is received is so small that shadows are sharp and may prove annoying. Diffusion of the light coming directly from the lamp is therefore important

and the use of bowl-frosted Mazda C lamps is recommended where there are polished surfaces at the work.

The dome unit, a mean between the flat and bowl types, became the standard for the majority of installations of Mazda B lamps and steel reflectors. The output of typical reflectors is 75 to 80 per cent of the light generated by the lamp; the percentage of light utilization is as high as with any enameled units. The large area of the reflector provides a source of illumination which tends to minimize the harshness of shadows.

Porcelain-Enameled
Flat Cone

Clear Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1168	40
0°-90°	2160	74
90°-180°	292	10
0°-180°	2454	84

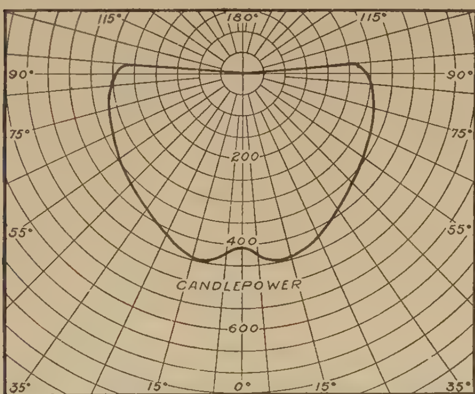


Fig. 68. Candle-Power Distribution Curve of Clear Lamp with Porcelain-Enameled Flat-Cone Reflector

After a thorough study of the requirements, the principal manufacturers of metal reflectors and the illuminating engineers of the Mazda lamp manufacturers have evolved a standard design which virtually combines the advantages of the older dome and bowl types. The angle of cut-off was made somewhat lower than in the old form of dome and this gave the required added protection from direct glare without appreciably sacrificing the effectiveness of the illumination. The new reflector is known as the Reflector and Lamp Manufacturers' (RLM) standard dome.

For special uses, angle-type porcelain-enameled reflectors are also available.

In the early days of electric lighting the use of clusters of incandescent lamps under porcelain reflectors of either the flat or dome type was common practice; in fact, it was the only way in which a light source of considerable candle-power could be obtained. In general, however, single units are preferable to clusters. One 400-watt, gas-filled lamp gives more light than

Porcelain-Enameled
Flat Cone, Shielding Band

Clear Lamp

Zone	Lumens	% Total Clear Lamp
0°-60°	1490	51
0°-90°	1900	65
90°-180°	29	1
0°-180°	1930	66

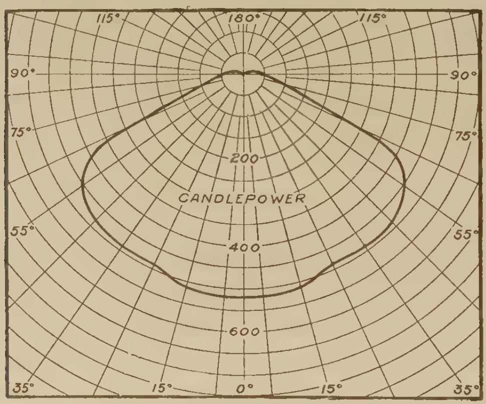


Fig. 69. Candle-Power Distribution Curve of Clear Lamp with Porcelain-Enameled Flat Cone Reflector and Shielding Band

five 100-watt units, and cross-absorption—the loss caused by the rays passing through more than one bulb—further reduces the efficiency of a cluster by an increasing amount as the bulbs darken, averaging about 10 per cent throughout the life of the lamps.

A reflector which, while it employs porcelain enamel for its principal reflecting surface, also makes use of a polished metal cap which is placed over the tip end of the lamp to redirect all the downward light upward against the porcelain-enameled surface whence it is thoroughly diffused and directed downward, is shown

in Fig. 67. The light from this unit is characterized by freedom from glare, and the shadows are soft with gradually fading outlines. This unit finds its principal use in industrial plants where lamps of 150 watts, or larger, are used and where reflections in polished surfaces would prove annoying if ordinary reflectors were employed. The use of a frosted lamp in a standard dome reflector, or an opal cap below the lamp, produces the same effect but to a lesser degree. On the other hand, dome reflectors with a cylindrical band of metal or glass around the lamps, Fig. 69, protect the eye well from direct glare but fail to diffuse the downward rays from the source.

DEFINITIONS

Diffusing Surfaces. Diffusing surfaces and media are those which break up the incident flux and distribute it more or less in accordance with the cosine law, as, for example, white plaster and opal glass.

Redirecting Surfaces. Redirecting surfaces and media are those which change the direction of the luminous flux in a definite manner; as, for example, a mirror or lens.

Reflection Factor. The reflection factor of a body is the ratio of the flux reflected by the body to the flux incident upon it. The reflection from the body may be regular, diffuse, or mixed. In regular reflection the flux is reflected at an angle of reflection equal to the angle of incidence. In diffuse reflection the flux is reflected in all directions.

Absorption Factor. The absorption factor of a body is the ratio of the flux absorbed by the body to the flux incident upon it.

Transmission Factor. The transmission factor is the ratio of the flux transmitted by the body to the flux incident upon it.

DIFFUSION OF LIGHT

As suggested in the preceding section, illuminating engineering is not wholly a matter of selecting and locating reflectors so as to throw the maximum light from the lamps in some predetermined direction. A knowledge of such other factors as glare, shadow quality, illumination of surrounding surfaces—in a word,

diffusion of light—is necessary before a lighting system can be intelligently planned.

Glare. The presence of glare is the most common defect of modern lighting systems. There are six principal causes:

1. Intrinsic brilliancy of the source.
2. Total candle-power from the source directed toward the eye.
3. Distance from the source to the eye.
4. Contrast in brightness between the light source and the working surfaces and surroundings.
5. Proximity of the light source to the line of vision.
6. The length of time during which the source of glare is present within the field of vision.

Glare has been defined as "light out of place." It may be more fully defined as any brightness within the field of vision of such a character as to cause discomfort, annoyance, interference with vision, or eye-fatigue. Always a hindrance to vision, it often, like smoke from a chimney, represents a positive waste of energy.

A glance at the sun proves that an extremely bright light source within the field of vision is capable of producing acute discomfort. Light sources of far less brilliancy than the sun, such, for example, as the filament of a Mazda lamp or the incandescent mantle of a gas lamp, are also quite capable of producing discomfort by direct glare, though the annoying effect is not usually so marked. Too frequently the consideration of glare is assumed to be entirely a question of intrinsic brilliancy of light source; of equal importance is the question of total light flux entering the eye. Tests have shown that a 10-inch opal globe equipped with a 500-watt Mazda C lamp, hung approximately 10 feet above the floor and 10 feet ahead of the observer, will prove quite as glaring as a bare 75-watt Mazda C lamp in the same location. Although the intrinsic brilliancy of the opal globe unit is only two or three times that of a candle flame, its total candle-power and hence the quantity of light which reaches the eye *at this close range* is so excessive that its effect is just as bad as that of the filament of the lower candle-power Mazda C lamp which has an *intrinsic brilliancy* of 3000 candle-power per square inch. On the other hand, the same 500-watt unit at twice the mounting height might be entirely unobjectionable, because a greatly reduced *quantity* of light would then reach the eye.

Determination of Values. From what has preceded it is to be seen that there are at least two distinct brightnesses which are of particular interest in connection with illumination problems. The more definite of these two is the brightness at which a given source looks just uncomfortably bright when viewed casually against a background. The second, and of much lower value, is the brightness at which a source proves tiring and causes fatigue when continually within the field of vision for a considerable period of time. The latter value is much more difficult to determine, and it apparently varies through wider limits for different individuals. What these values represent may, perhaps, be more clearly understood by considering the analogous case of looking out of a window which by day is a source of light for a room. Unless the room is very dark or the landscape very brilliant, the effect of looking out of the window for a moment will not be at all unpleasant, but to sit all day facing the window would prove extremely tiring, even if one were sitting at a desk or table and not paying particular attention to the window. This window is exactly comparable to a light source which is not bright enough to cause an immediate sensation of glare but too bright to be viewed continuously.

The problem of determining definite limiting values for these two conditions of glare is rendered extremely difficult because of the fact that the extent to which glare is objectionable is partially dependent upon the contrast in brightness between the light source and the background. This is illustrated by the fact that although automobile headlights as seen at night are likely to be so glaring as to be temporarily blinding, the same lights would in the daytime hardly be noticed. The permissible brightness of a light source is greater when the general illumination is of high intensity than when it is of low intensity. That is, for a room which has dark walls and furnishings, a unit of lower brightness should be used than might be found comfortable in a well-illuminated room in which the decorations are light in color. The permissible ratio between source brightness and background brightness is not, however, constant; the ratio is smaller at high values of intensity than at low ones. In fact, investigation by Dr. Nutting has indicated that increasing the brightness of the

TABLE X

Brightness of Artificial Light Sources

	Approximate C-p. per Square Inch	Millilamberts
Crater of carbon arc	83800	40800000
Flaming-arc clear globe	5000	2435000
Magnetite arc	4000	1945000
Filament of gas-filled tungsten lamp	2880	1400000
Filament of vacuum tungsten lamp (1.25 W.P.C.)	1060	516000
Quartz tube, mercury-vapor arc	1000	486700
Filament of carbon lamp (3.1 W.P.C.)	485	236000
Welsbach mantle	31	15080
Cooper-Hewitt glass-tube mercury-vapor lamp	14	6800
Candle flame	3	1400
Sky, average brightness	4–2	2000–1000
Side of 25-watt frosted lamp	6	2900
Bowl-frosted, 100-watt, gas-filled lamp	50	25000
Ten-inch, opal-ball enclosing, 100-watt tungsten lamp	0.6	300
Twenty-inch dome with concealed source, 200-watt lamp	2	930

background *ten times* only permits of *doubling* the brilliancy of the light source if the sensation of glare is to be avoided.

Ordinarily the brightness of a lighting unit which is in the central portion of the visual field should not exceed from 2 to 3 candles per square inch of apparent area (1 to 1½ lamberts), if that unit is not to give rise immediately to a sensation of glare, and the brightness should be reduced to one-half candle per square inch of apparent area (.25 lamberts) if it is not to fatigue the eyes when viewed continually. In this connection it is interesting to note from Table X that the candle is the only unmodified light source that would not be classed as immediately glaring when measured by these criteria, and on the other hand, that the brightness of the sky rarely exceeds 3 candles per square inch. A 200-watt Mazda C lamp in a 10-inch opal ball of medium-density glass will emit light of an intensity of about 180 candles (the opal ball so diffuses the light that the candle-power in all directions from the unit is approximately the same). The apparent area of a ball 10 inches in diameter is about 80 square inches, hence the opal ball is a source emitting 2¼ candles per square inch of apparent area. Such a unit would be too bright for an office, but would be satisfactory for hallways, store rooms, and similar

places which are used intermittently, and for many stores and industrial plants where those using the illumination frequently move about and are not called upon to face the lighting units for long periods. If a 60-watt lamp were substituted for the 200-watt in the 10-inch ball referred to, the brightness would be reduced to slightly more than ½ candle per square inch, and this would usually be the largest lamp that could be used in a medium-density opal ball of this size if all danger of glare were to be avoided with the unit placed in an office or a similar location.

Where the direct light from sources in the field of vision causes glare, it is sometimes possible to improve poor lighting conditions by changing the position of the sources. Little interference with vision is evident where light sources are from 25 to 30 degrees away from the normal line of sight; but even when so located they are quite capable of producing eye-fatigue if continually within the range of vision.

Specular Reflection. A form of glare which is often less obvious than that which comes direct from the source to the eye, but which is frequently more harmful because of its insidious nature, is that which comes to the eye as glint or a reflection of the source in some polished surface. This form of glare, known as specular reflection or veiling glare, is frequently encountered where the work is with glossy paper, polished metal or furniture, or other shiny or oily surfaces, and is particularly harmful because of the fact that the eye is often held to such surfaces for long periods of time, and, further, because the eye is especially sensitive to light rays entering from below. While the glare may not be sufficiently annoying to be recognized as of a serious nature, it will nevertheless in time produce eye-fatigue or even permanent injury. Since the brightness of the reflected image is dependent upon the brightness of the light source, it follows that the harmful effects of specular reflection can be minimized by reducing the brightness of the light source. Frequently, specular reflections can be prevented from striking the eye by locating the light source in such a position with respect to the work that specularly reflected light will be thrown away from, rather than toward, the worker. The use of lighting units of large area and a diffusing medium to prevent any direct rays from

the lamp striking the surfaces illuminated will aid in preventing bad specular reflection, but, on the other hand, if the source is very large, as, for example, a ceiling lighted by indirect units, a certain amount of specular reflection cannot be avoided. For a machine shop a more highly diffusing light source will be required than for a wood-working shop, because the reflected images from metal are much more distinct than those from wood.

Shadow. Shadows may be troublesome if they are sharp or so dark that it becomes difficult to distinguish between them and objects, or if the illumination in the shadows is insufficient for good vision. With general lighting, shadows from the work or fixed objects can be modified by placing the light units high and close together. A maximum degree of shadow results in the case of direct-lighting systems using clear-bulb lamps in open reflectors of small area;

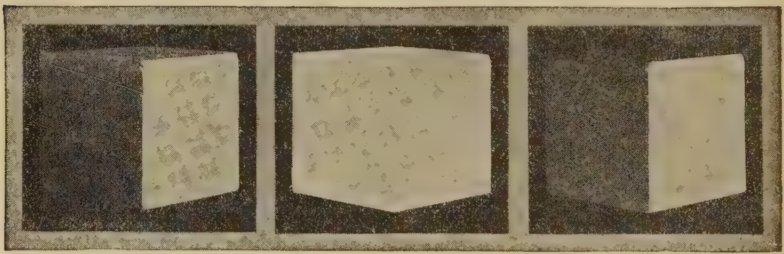


Fig. 70. White Cube Lighted from Various Directions

a minimum in that of totally indirect lighting systems. Enclosing and semi-enclosing units produce shadows which are softer than those produced by open reflectors but much heavier than those produced by totally indirect systems. With semi-indirect units, almost any degree of shadow can be obtained by varying the density of the glass.

In observing objects in their three dimensions, shadows are an aid to vision in that the surfaces can be more easily distinguished from one another than if they are all lighted to the same intensity. Fig. 70, reproduced from photographs, shows the power of light to change appearance. However, while shadows are of great value in the discernment of irregularities of surfaces, they are of little or no value in the observation of plain surfaces. For example, while shadows are highly desirable in industrial

work, in offices they are unnecessary, and, in fact, often a decided nuisance. With few exceptions, only soft, luminous shadows are desirable in interior lighting; those having sharp edges or a series of sharp edges are objectionable.

Illumination of Vertical Surfaces. For many locations, such as offices and drafting rooms, light is required principally on horizontal planes, such as desk tops or table tops, and it has been the custom to calculate illumination on the basis of that delivered to horizontal surfaces with the assumption that the oblique surfaces of objects would be sufficiently lighted. This practice may result in inadequate illumination. In a machine shop, for example, the lighting of the vertical surfaces of the work or of machine parts is fully as important as the lighting of the horizontal surfaces. As a matter of fact, most shops are lighted during the day only by light from windows, which give a greater light on the vertical surfaces than on the horizontal. In all such cases where direct lighting is used, only those lighting units should be installed which show a reasonably good candle-power in the 50–70 degree zone as well as below these angles. A shop lighted by closely spaced automobile headlights directing the light downward from the ceiling would furnish ample light on a horizontal plane, but such lighting would be far from satisfactory.

Desirable Wall Brightness. The effectiveness of a lighting system depends not only on the effectiveness of the lighting unit, but on the reflecting properties of the walls, ceiling, and surroundings, and upon the proportions of the room. It is, in fact, entirely possible to find an installation of reflectors of poor design and inferior from the standpoint of glare, which is nevertheless, from the single criterion of the percentage of light reaching the illumination plane, better than an installation where reflectors of good design are used, if the former are installed under favorable conditions such as light walls, ceiling, etc., and the latter under unfavorable conditions. On the other hand, it must be borne in mind that a large expanse of light wall surface so finished as to reflect a large volume of light into the eye is objectionable for offices, residences, and all rooms where the occupants are likely to sit with the walls directly in view for considerable periods of time. Such data as are available indicate

that where the brightness of the wall is equal to, or greater than, the brightness of a sheet of white paper lying on an adjacent table or desk, annoying glare will result. *In fact, a wall brightness of even one-half that of the paper on one's desk has been found unsatisfactory—a brightness of 20 per cent is, apparently, comfortable.* With the usual types of lighting units, walls are not illuminated to intensities as high as those obtaining on desk or table tops, and therefore walls which reflect less than 50 per cent of the light which strikes them should not produce discomfort, providing, of course, that they are of a mat or semi-mat finish. Walls finished in buff, light green, or gray reflect about the proper proportions of light and their use is meeting with general favor. Walls finished in a high gloss are not satisfactory from a glare standpoint.

PLANNING A LIGHTING SYSTEM

The requirements to be met in the choice of reflecting equipment and in the design of a satisfactory lighting installation are:

1. Sufficient light of unvarying intensity on all principal surfaces, whether in horizontal, vertical, or oblique planes.
2. A comparable intensity of light on adjacent areas and on the walls.
3. Light of a color and spectral character suited to the purpose for which it is employed.
4. Freedom from glare and from glaring reflections.
5. Light so directed and diffused as to prevent objectionable shadows or contrasts of intensity.
6. A lighting effect appropriate for the location and lighting units which are in harmony with their surroundings, whether lighted or unlighted.
7. A system which is simple, reliable, easy of maintenance, and in initial and operating cost not out of proportion to the results attained.

Complete satisfaction cannot be expected from an installation in which any one of these requirements has been neglected. As has already been mentioned there are but two electric illuminants which are frequently considered for interior lighting today, the incandescent lamp and the mercury-vapor lamp.

Chief Systems of Illumination. There are three general systems of illumination which have come to be classified in accordance with the manner in which the light is distributed:

Direct-lighting systems
Indirect-lighting systems
Semi-indirect-lighting systems

Direct-Lighting Systems. In direct lighting the light is sent direct to the surfaces to be illuminated. Reflectors or enclosing glassware are used to improve the distribution of the light and to diffuse the direct rays from the lamp, and to increase the apparent size of the source. With open reflectors, both direct glare from the lamp and glaring reflections are modified by frosting the lamp and by using a reflector of large area. These measures will also have the effect of softening the shadows. Illumination of vertical surfaces can be accomplished by selecting a unit having a distribution of light which is not too concentrating.

Units may either be placed close to the individual objects or work which it is desired to illuminate, known as local lighting, or they may be mounted well up near the ceiling, and from this location distribute an approximately uniform illumination over the entire area, known as general illumination. Because of their location at or below the eye level, individual lights must be especially well shaded, and in almost all such installations the addition of a certain amount of general illumination is an absolute necessity; first, to make it possible to move about the room in safety, and second, to reduce brightness contrasts to a ratio tolerable to the eye. For most utilitarian installations the better course is to install an adequate overhead lighting system and eliminate drop cords entirely.

Indirect-Lighting Systems. In indirect lighting the ceiling and walls redirect and diffuse all the light emitted by the units. Since the ceiling acts as the light source, with the maximum distribution directly downward, glare from the unit is avoided, and shadows are soft, but for a given illumination on horizontal surfaces there is usually less illumination on vertical surfaces than with other systems. For some locations, shadows are not sufficiently defined to be of much assistance in the discernment of small surface irregularities.

Semi-Indirect Lighting Systems. In semi-indirect lighting the features of the direct and indirect systems are combined. With a correctly designed bowl of dense-opal glass, the brightness of the unit is low enough to avoid eye-fatigue, and sufficient direct light is emitted to produce the proper degree of vertical illumination and the soft or graded shadows often desired. A light-density opal may be used in certain locations where the

units are hung high and the nature of the work is such that they are not in the usual range of vision.

Selection of System. The characteristics of the room to be lighted are important in the selection of a lighting system. The presence of large quantities of dust usually discourages even a consideration of indirect and semi-indirect systems for industrial lighting. The dark tone of the walls and ceiling in factories also tends to preclude the use of these systems. Cost and efficiency are factors which may limit the choice, although the present tendency in industrial lighting, particularly in the more specialized manufacturing branches, is to make good lighting the first consideration. It may well be mentioned that in connection with the lighting the liberal use of paint or whitewash can hardly be too strongly recommended.

In residence, store, office, and public-building lighting, the system must be of good appearance and in harmonious relation with the decorative and architectural features of the surroundings. Incandescent lamps in semi-indirect and enclosing units lend themselves most readily to these classes of service if the color of the ceiling and walls permits their use. It should always be borne in mind, however, that such units, to be satisfactory as to glare, must be selected with care in accordance with the suggestions previously given. Totally indirect units, on the other hand, are practically certain to be satisfactory from this standpoint.

In the choice of a lighting unit the question of color must be considered, both that of the illuminant itself and of the reflecting equipment as well. For esthetic reasons warm tones are often preferred. For the discrimination of fine detail a monochromatic light, such as the mercury vapor, is sometimes of advantage. Under certain conditions the principal criterion is the penetrating power of the light, and here the appearance of the sun through fog or smoke evidences the fact that a preponderance of red and yellow rays is most effective. For color matching and for certain other operations in which objects are most easily differentiated or identified by their color, a light source closely approximating daylight in spectral character is to be sought.

Aside from the renewal of lamps, and breakage, depreciation of the light output of a unit due to the collection of dust is

usually the largest item to be considered from the standpoint of maintenance. It is evident that lighting units which have concave reflecting surfaces opening upward will collect dirt much more quickly than if the surfaces opened downward. The contour should be simple and the exposed surfaces smooth in order to expedite frequent cleaning of the units.

From the many lighting units on the market, a selection of a certain unit should first be made on a basis of its characteristics with regard to absence of direct glare, glaring reflections, and sharp shadows, the nature of its light distribution as adapted to the nature of the work and to the possible spacing and hanging height. The consideration of appearance, efficiency, maintenance, and cost will then determine which unit to select. The distributions of units included in the section "Reflectors and Enclosing Glassware" and the comparative data shown in Table XI should prove of considerable assistance to one in arriving at a choice.

Choice of Intensity. The eye is capable of adapting itself to see under illumination intensities which range from a small fraction of a foot-candle to several thousand foot-candles in value. At very low intensities the eye does not receive sufficient light to enable it to distinguish color or detail, and at very high values, a blinding effect which also obliterates detail is experienced. Between these limits there is a wide range of intensities where good vision is possible. Considerations of economy usually limit the intensities employed in artificial lighting to the lower values of this range. So closely is the lower limit approached that it is necessary in designing a lighting installation to take into consideration such factors as the color of the objects requiring illumination—for objects are seen by the light which they reflect, and dark objects require higher intensities than light ones for equally good vision; the order of brightness of surroundings; the amount which it is considered expedient to apportion for the advertising value of a high intensity; and the intricacy of the work which is performed under the artificial lighting. For example, a jewelry store in a small town may be brightly lighted at an intensity of 4 foot-candles, whereas a jewelry store located on a prominent business street in a large city will require, to be considered well lighted, an intensity of perhaps 6 or 8 foot-candles. Again, the

TABLE XI

A Guide to the Selection of Reflecting Equipment*

Lighting Unit		Horizontal Illumination	Vertical Illumination	Favorable Appearance of Lighted Room	Direct Glare	Reflected Glare	Shadows	Maintenance
R L M Dome, Clear Lamp	90° to 180°—0%; 0° to 90°—75%	A+	A+	C+	C	D	C+	A+
R L M Dome, Bowl Frosted Lamp	90° to 180°—0%; 0° to 90°—71%	A	A	B	B	C	B	B+
R L M Dome, Opal Cap	90° to 180°—0%; 0° to 90°—66%	B+	B+	B	A	B	A	C+
Steel Bowl, Clear Lamp	90° to 180°—0%; 0° to 90°—65%	B+	B	C	C+	D	C	A
Steel Bowl, Bowl Frosted Lamp	90° to 180°—0%; 0° to 90°—60%	B	B	C	B	C	C+	B+
Reflecto-Cap Diffuser, Silver Cap	90° to 180°—0%; 0° to 90°—55%	B	C+	B	A	B+	A+	C+
Flat Steel, Clear Lamp	90° to 180°—10%; 0° to 90°—74%	B	A	C	D	D	C	A+
Flat Steel, Shielding Band	90° to 180°—1%; 0° to 90°—65%	B+	B+	C+	C+	D	C	B+
Mirrored Glass, Clear Lamp	90° to 180°—0%; 0° to 90°—68%	A	B+	C	C+	D	C	A
Prismatic Industrial, Clear Lamp	90° to 180°—18%; 0° to 90°—73%	A	A+	B+	C+	D	C+	B

Courtesy of Engineering Department, National Lamp Works of General Electric Company.

*A+ ....Best
A ....Excellent
B+.........Very Good
B...............Good
C+ ....Fair
C...............Weak
D...............Condemned

Various lighting units are rated in accordance with seven fundamentals. The order of importance of these criteria is different for different classes of service. In a drafting room, for example, the elimination of shadow is of far more importance than the illumination of vertical surfaces, whereas in the lighting of a furniture show room the reverse is true.

The grades assigned to the different equipments are relative and apply only when the units are used with the same size of Mazda C lamp and under similar conditions. In some cases individual units so far excel the others of the same group as to warrant a higher classification than is here given.

TABLE XI—Continued

A Guide to the Selection of Reflecting Equipment—Continued*

Lighting Unit		Horizontal Illumination	Vertical Illumination	Favorable Appearance of Lighted Room	Direct Glare	Reflected Glare [3]	Shadows	Maintenance
Prismatic Intensive, Bowl Frosted Lamp	90° to 180°—21%; 0° to 90°—59%	B+	B	A	B	C	B	C+
Light Density Opal, Bowl Frosted Lamp	90° to 180°—34%; 0° to 90°—51%	B	B	A	B	C	B+	C+
Dense Opal, Bowl Frosted Lamp	90° to 180°—20%; 0° to 90°—60%	B+	B	A	B+	C	B	B
Diffusing Globe, Light Opal	90° to 180°—35%; 0° to 90°—40%	C+	B	A	C+	C+	B	A
Diffusing Globe, With Reflector [1]	90° to 180°—6%; 0° to 90°—58%	B	B+	B+	B	C+	B+	B+
Semi-Enclosing, Opal Bowl [2]	90° to 180°—20%; 0° to 90°—60%	B	B+	A	B+	B	A	C+
One-Piece Enclosing, Dense Opal	90° to 180°—17%; 0° to 90°—55%	B	B	A	A	B+	A	A
Semi-Indirect, Light Opal	90° to 180°—60%; 0° to 90°—25%	C+	C	A	A	B+	A	C
Semi-Indirect, Dense Opal	90° to 180°—70%; 0° to 90°—10%	C	C	A	A+	A	A+	C
Indirect, Mirrored Glass	90° to 180°—80%; 0° to 90°—0%	C	C	B+	A+	A	A+	C

Courtesy of Engineering Department, National Lamp Works of Genera Electric Company.

* 1. If globes are very large, rate B on glare; if very small, C.

2. Rate C+ on glare if the bowl is noticeably brighter than the upper reflector.

3. Ratings apply only where work is being done on polished or oily surfaces.

Maintenance depends on contour of reflector, construction of fixture, and condition of ceiling. The rating is based on labor involved in maintaining the units at comparable degrees of efficiency, and on the likelihood of the need for cleaning being apparent.

The column headed "Favorable Appearance of Lighted Room" refers *only* to the general or casual effect produced by the complete system, and is not intended to rate the unit as to its satisfaction from the standpoint of good vision or freedom from eye-fatigue.

TABLE XII

Present Standard of Illumination

		Foot-Candles
Auditorium, Church		1.5–3
Armory, Public Hall		2–4
School	Classroom, study room, library	3–6
Store	Show window	10–50
	First-floor department, shop on bright street or corner	7–10
	Other clothing, dry goods, haberdashery, millinery, jewelry, etc.	4–7
	Other drug, grocery, meat, bakery, book, florist, furniture, etc.	3–5
Office	Private, general	4–8
	Drafting room	8–12
Industrial*	For rough manufacturing occupations, such as rough assembling, rough forging, rough woodworking, ice-making, potteries, lumber mills, tanneries, etc.	3–6
	For medium manufacturing occupations, such as medium woodworking, rough machining, rough bench work, automatic-machine work, meat packing, paper-making, laundries, bakeries, etc.	4–8
	For fine manufacturing occupations, such as fine assembling, leather-working, fine woodworking, fine lathe work, tobacco manufacturing, fine sheet-metal working, manufacturing light-colored textiles, etc.	6–12
	For extra-fine manufacturing occupations, such as watch and jewelry manufacturing, engraving, typesetting, shoe manufacturing, enameling, manufacturing dark-colored textiles, etc.	8 and up
Building Exterior		3–15

* It must be remembered that, other things being equal, work on dark goods requires a higher illumination than work on light goods.

cloak and suit department of a large store will require a higher intensity than will the white-goods department. An industrial plant engaged in rough-box manufacture would be well lighted at an intensity of 4 foot-candles; in a high-grade machine shop an intensity as high as 8 or 10 foot-candles would be desirable. The values given in Table XII have been established by experience and used by various authorities as standard in current practice. Bearing in mind the character of the work, the fineness of detail

to be observed, and the standard of lighting of the immediate surroundings, one should be able to select a suitable intensity from the range of intensities given to serve as a basis for illumination calculations. It should be remembered, though, that the intensity so chosen can rarely be exactly provided in practice, and it should be considered simply as an assumed desirable value which permits the calculations to be carried through.

Light Losses. The average light output of modern incandescent tungsten lamps throughout rated life is about 94 per cent of the initial value, and the collection of dust on the lamps and reflectors in service will produce an additional loss of light, the

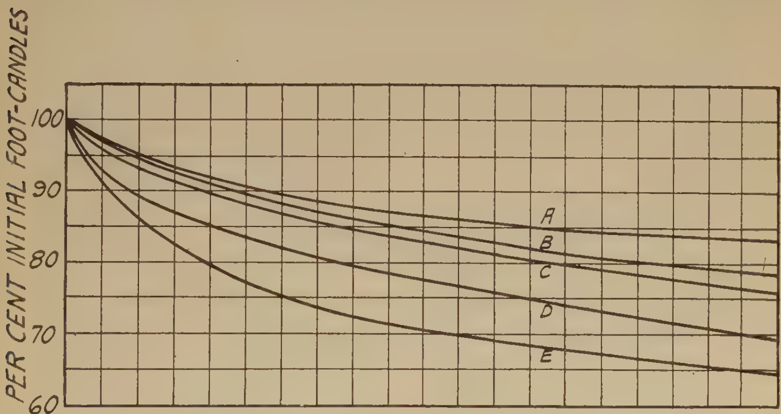


Fig. 71. Effect on Illuminating Intensity of Dust Collection on Lamps and Reflectors. *A*, Enameled-Steel Dome; *B*, Enameled-Steel Bowl; *C*, Dense Opal Glass; *D*, Prismatic Glass; *E*, Light-Density Opal Glass

amount depending upon the frequency of cleaning and the conditions of service. Open reflectors cleaned at regular intervals of from two to six weeks ordinarily show a loss of from 5 to 20 per cent at the end of the period, depending upon the type, Fig. 71. With an indirect system the depreciation is perhaps twice as rapid as for the same unit pendent. Experience has shown that an increase over the desired average intensity of 20 per cent may be taken to cover both the decrease in lamp output and the dust depreciation under best conditions; in a foundry, or a roundhouse, an increase of 40 per cent would not be excessive. Since the actual intensity received from a lighting system should average not less than the value selected from the table, the value selected

should be multiplied by a "depreciation factor" of from 1.20 to 1.40, depending upon existing conditions and the type of fixture, in order that the decrease from the initial intensity will not cause the average illumination to fall below the desired value. The depreciation due to dust in the case of the mercury-vapor lamp is comparable to that of an incandescent lamp in a dome reflector, but the average candle-power of the tube itself is a somewhat lower percentage of the initial (see Fig. 29), hence a correspondingly greater depreciation factor should be allowed.

The finish of the walls and ceiling of an office affects to a considerable degree the efficiency of a lighting installation. Investigation of a complaint of inadequate office illumination, where the system consisted of indirect silvered-glass units properly located, disclosed the following facts:

	Foot-candles	Per cent
Before cleaning reflectors	3.75	100
After cleaning reflectors	4.68	125
Cleaned reflectors—new lamps	5.26	140
Cleaned reflectors—new lamps—repainted ceiling	6.78	181

The original finish of the ceiling was a yellowish-cream paint on sand-surfaced plaster. This had become somewhat blackened during two years' service. It will be noted that refinishing the ceiling with paint of good reflecting characteristics and of a somewhat lighter tone than that previously used resulted in an increase of 30 per cent in useful light.

Owing to the loss of light through absorption by the reflector or enclosing glassware, by the fixture, and by the walls and ceiling, only a part of the total light emitted by a lamp reaches the designated plane. Of the light sent in directions other than those where it is used, some will be redirected by the ceiling, walls, and other surfaces on which it falls, and the percentage of the total lumens emitted by the lamp which ultimately reaches the desired location will, therefore, vary widely with the proportions of the room and the nature of the surroundings. Contrary to the general belief, the absolute height in feet at which units are mounted has in itself no influence upon the percentage of light utilized, so long as the same proportions are maintained. For example, if there are two buildings, one 20 feet by 50 feet and 10 feet in height, and the other 40 feet by 100 feet and 20 feet in height, it is

clear from Fig. 72 that the effective angle and hence the efficiencies of the lighting systems in the two buildings will be the same. If the small building is illuminated by eight 100-watt

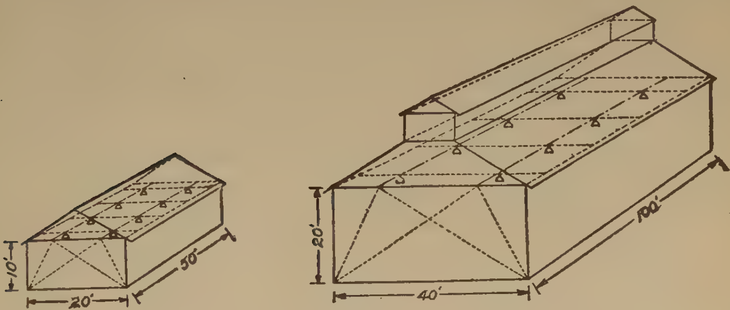


Fig. 72. Diagram Illustrating Effective Angle of Lighting

lamps on 10-foot centers and the large building by the same number of 400-watt lamps on 20-foot centers, the average intensity of illumination will be the same, neglecting the difference in the efficiency of the lamps, and the distribution of light will be similar. On the other hand, the *proportions* of a given building or room have a very important bearing upon the percentage of light utilized. In Table XIII are shown the coefficients of utilization, as the percentages are called, for the more common reflecting equipments when used in square rooms. For rooms in which the ratio of width to ceiling height is small a low utilization obtains, because, as shown in Fig. 73, a relatively greater portion of the light strikes and is absorbed by the walls than is the case in a large room.

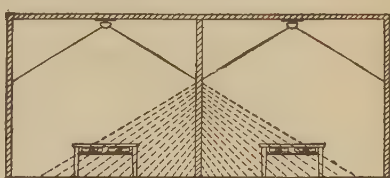


Fig. 73. Light Striking Partition Is Largely Lost

A criterion called "room ratio" has been established to take this factor into account; formerly it was evaluated simply by dividing the room width by the ceiling height. A more accurate method of computing this ratio is, however, shown at the top of Table X. For areas having room ratios between those given in the table, proportionate values should be used; where the room ratio exceeds 5, the increase in the coefficient is so slight as to be negligible and the coefficient for a

COEFFICIENTS OF UTILIZATION

The proportion of the total light from the lamps reaching the plane of the work is the Coefficient of Utilization of an installation. For a given reflector equipment the Coefficient is dependent upon the color of the ceiling and walls, and upon the "Room Ratio", which is the relative width of the room compared with the height of the light sources above the level of the work. This table of Coefficients applies to installations having sufficient lighting units symmetrically arranged to produce reasonably uniform illumination.

SQUARE ROOMS—To find Coefficient of Utilization,

(1st) Determine Room Ratio.

For DIRECT installations, (first 16 units of table),

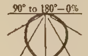
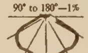
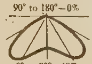
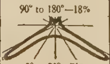
$$\text{Room Ratio} = \frac{\text{width of room}}{2 \times \text{height from plane of work to } \textit{lamps}}$$

For INDIRECT and SEMI-INDIRECT installations, (last 4 units of table),

$$\text{Room Ratio} = \frac{\text{width of room}}{1\tfrac{1}{3} \times \text{height from plane of work to } \textit{ceiling}}$$

(2nd) Find Coefficient in proper column of ceiling and wall colors opposite this Room Ratio value.

RECTANGULAR ROOMS—Find the Coefficient as above for a square room of the narrow dimension and add one-third of the difference between this value and the Coefficient for a square room of the long dimension.

Color (Reflecting Value) of Ceiling			Light (70%)			Medium (50%)		Dark (30%)
Walls			Light (50%)	Medium (35%)	Dark (20%)	Medium (35%)	Dark (20%)	Dark (20%)
Reflector Type	Light Output	Room Ratio	Coefficients of Utilization					
B L M DOME  Clear Lamp	90° to 180°—0%  0° to 90°—76%	1	.46	.43	.41	.42	.40	.40
		1½	.54	.51	.48	.50	.47	.47
		2	.60	.57	.54	.56	.53	.53
		3	.65	.62	.60	.61	.59	.59
		5	.69	.67	.65	.66	.65	.64
B L M DOME  Bowl-Frosted Lamp	90° to 180°—0%  0° to 90°—73%	1	.45	.42	.40	.41	.39	.38
		1½	.52	.49	.47	.48	.46	.46
		2	.56	.53	.51	.52	.50	.50
		3	.62	.60	.57	.58	.56	.56
		5	.66	.65	.63	.63	.62	.62
B L M DOME  Opal Cap	90° to 180°—0%  0° to 90°—66%	1	.40	.37	.35	.37	.34	.34
		1½	.47	.44	.42	.44	.42	.42
		2	.51	.48	.46	.48	.46	.46
		3	.56	.54	.52	.53	.51	.51
		5	.60	.58	.57	.57	.56	.55
ENAMELED BOWL  Clear Lamp	90° to 180°—0%  0° to 90°—65%	1	.38	.36	.34	.35	.33	.33
		1½	.45	.43	.41	.42	.40	.40
		2	.49	.47	.45	.46	.44	.44
		3	.54	.52	.50	.51	.49	.49
		5	.59	.57	.55	.56	.54	.54
ENAMELED BOWL  Bowl-Frosted Lamp	90° to 180°—0%  0° to 90°—60%	1	.37	.34	.32	.33	.31	.31
		1½	.43	.40	.38	.39	.37	.37
		2	.46	.44	.42	.43	.41	.41
		3	.51	.49	.47	.48	.46	.46
		5	.55	.53	.52	.52	.51	.50
METAL-CAP DIFFUSER  Silver Cap	90° to 180°—0%  0° to 90°—55%	1	.33	.31	.30	.31	.29	.29
		1½	.39	.37	.35	.36	.34	.34
		2	.43	.41	.39	.40	.38	.38
		3	.47	.45	.43	.44	.42	.42
		5	.50	.49	.47	.48	.47	.46
FLAT CONE  Clear Lamp	90° to 180°—10%  0° to 90°—74%	1	.36	.31	.28	.30	.28	.27
		1½	.44	.39	.36	.37	.35	.35
		2	.50	.46	.42	.44	.41	.41
		3	.56	.53	.48	.51	.47	.47
		5	.62	.59	.54	.57	.53	.53
FLAT CONE  Shielding Band	90° to 180°—1%  0° to 90°—65%	1	.38	.36	.34	.35	.33	.33
		1½	.44	.42	.40	.41	.39	.39
		2	.49	.47	.45	.46	.44	.44
		3	.54	.52	.50	.51	.49	.49
		5	.58	.56	.55	.55	.54	.53
MIRRORED GLASS  Clear Lamp	90° to 180°—0%  0° to 90°—68%	1	.44	.41	.39	.41	.39	.38
		1½	.50	.47	.45	.47	.45	.44
		2	.55	.52	.50	.52	.50	.49
		3	.59	.57	.55	.56	.54	.54
		5	.63	.61	.59	.59	.58	.58
PRISMATIC INDUSTRIAL  Clear Lamp	90° to 180°—18%  0° to 90°—73%	1	.46	.42	.39	.40	.37	.36
		1½	.54	.50	.47	.48	.45	.44
		2	.60	.56	.53	.54	.51	.50
		3	.67	.64	.61	.61	.58	.56
		5	.73	.70	.67	.67	.64	.62

EXAMPLES ILLUSTRATING USE OF TABLE

(a) Find the Coefficient of Utilization for an RLM Dome, clear lamp, direct installation in a rectangular room 40′ x 120′; ceiling height, 27′; lamps mounted 20′ above the plane of work; plane of work 3′ above the floor; ceiling color, light; wall color, medium.

For a square room, narrow dimension,

$$\text{Room Ratio} = \frac{40}{2 \times 20} = 1.00 \qquad \text{Coefficient} = .43$$

For a square room, long dimension,

$$\text{Room Ratio} = \frac{120}{2 \times 20} = 3.00 \qquad \text{Coefficient} = .62$$

Coefficient of Utilization for the rectangular room with RLM Dome, clear lamp units is then,

$.43 + \frac{1}{3}(.62 - .43) = .49$ Ans.

(b) In the same room with an indirect, clear lamp installation, find the Coefficient of Utilization as follows:

For a square room, narrow dimension,

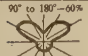
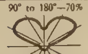
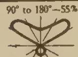
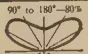
$$\text{Room Ratio} = \frac{40}{1\frac{1}{3} \times 24} = 1.25 \qquad \text{Coefficient} = .21$$

For a square room, long dimension,

$$\text{Room Ratio} = \frac{120}{1\frac{1}{3} \times 24} = 3.75 \qquad \text{Coefficient} = .35$$

Coefficient of Utilization for the rectangular room with indirect, clear lamp units is then,

$.21 + \frac{1}{3}(.35 - .21) = .26$ Ans.

Color (Reflecting Value) of Ceiling			Light (70%)			Medium (50%)		Dark (30%)
Walls			Light (50%)	Medium (35%)	Dark (20%)	Medium (35%)	Dark (20%)	Dark (20%)
Reflector Type	Light Output	Room Ratio	Coefficients of Utilization					
UNIT DENSITY OPAL  Bowl-Frosted Lamp	90° to 180°—34%  0° to 90°—51%	1 1½ 2 3 5	.34 .41 .47 .53 .59	.31 .38 .44 .50 .56	.28 .35 .41 .47 .53	.29 .35 .40 .45 .50	.26 .33 .38 .43 .48	.24 .30 .35 .40 .45
DENSE OPAL  Bowl-Frosted Lamp	90° to 180°—20%  0° to 90°—60%	1 1½ 2 3 5	.40 .47 .52 .58 .62	.37 .44 .48 .55 .60	.34 .41 .46 .52 .58	.35 .42 .46 .52 .57	.33 .39 .43 .49 .55	.32 .38 .42 .47 .52
DIFFUSING GLOBE  With Reflector	90° to 180°—6%  0° to 90°—58%	1 1½ 2 3 5	.31 .37 .42 .47 .51	.28 .34 .39 .44 .49	.26 .32 .37 .42 .46	.28 .33 .38 .43 .48	.25 .31 .36 .41 .46	.25 .31 .36 .41 .45
DIFFUSING GLOBE  Light Opal	90° to 180°—35%  0° to 90°—40%	1 1½ 2 3 5	.23 .30 .35 .41 .48	.20 .26 .31 .37 .44	.17 .23 .28 .34 .41	.18 .24 .28 .33 .39	.16 .21 .25 .30 .36	.14 .19 .22 .26 .31
SHALLOW REFLECTOR  Diffusing Bowl	90° to 180°—20%  0° to 90°—60%	1 1½ 2 3 5	.32 .40 .45 .52 .59	.28 .36 .41 .47 .54	.26 .33 .38 .44 .51	.27 .34 .39 .45 .51	.25 .32 .37 .42 .48	.23 .30 .35 .40 .46
ONE-PIECE UNIT  Reflector and Bowl	90° to 180°—17%  0° to 90°—55%	1 1½ 2 3 5	.32 .39 .44 .49 .54	.28 .35 .40 .45 .50	.26 .33 .38 .43 .48	.28 .34 .39 .44 .49	.25 .31 .36 .41 .46	.25 .30 .35 .40 .45
SEMI-INDIRECT  Light Opal	90° to 180°—60%  0° to 90°—25%	1 1½ 2 3 5	.27 .34 .39 .45 .51	.24 .30 .35 .41 .47	.21 .27 .32 .38 .44	.20 .25 .29 .34 .40	.17 .22 .26 .31 .37	.14 .18 .21 .25 .29
SEMI-INDIRECT  Dense Opal	90° to 180°—70%  0° to 90°—10%	1 1½ 2 3 5	.24 .30 .34 .39 .45	.21 .27 .31 .36 .42	.19 .24 .28 .33 .39	.16 .20 .23 .27 .32	.14 .18 .21 .25 .30	.10 .13 .15 .18 .21
PORCELAIN-ENAMELED INVERTED  Diffusing Plate Bottom	90° to 180°—55%  0° to 90°—16%	1 1½ 2 3 5	.25 .30 .34 .38 .43	.22 .27 .31 .36 .41	.20 .25 .29 .34 .40	.18 .22 .25 .29 .33	.17 .21 .24 .28 .32	.14 .17 .19 .22 .24
INDIRECT  Clear Lamp	90° to 180°—80%  0° to 90°—0%	1 1½ 2 3 5	.22 .27 .31 .36 .42	.19 .24 .28 .33 .39	.17 .22 .26 .31 .37	.14 .17 .20 .24 .28	.12 .15 .18 .22 .26	.07 .09 .11 .13 .16

ratio of 5 should be used. For rectangular rooms, the coefficient of utilization may be determined by adding to the coefficient for a square room of the short dimension, one-third the difference between this value and the coefficient for a square room of the long dimension. For example, coefficient for light density semi-indirect units used in a store with light ceilings and walls 18 feet wide by 120 feet long, with a ceiling 12 feet high—9 feet above the counters—is found as follows: The ratio for a room 20 feet square, and of the height designated, is $18 \div 1\frac{1}{3}(9) = 2$, and the corresponding coefficient is .34; the room ratio for the long dimension is 10, and the coefficient .51; then the coefficient for our room is $34 + \frac{1}{3}(.51 - .34) = .40$ Ans. It should be noted that this figure is not the same as would be obtained by finding the coefficient applicable to a single square room of equal area, or to a single square room whose length and breadth are equal to the average of the length and breadth of the rectangular room. Data for dome steel reflectors and clear-bulb lamps also apply to trough reflectors used with Cooper-Hewitt lamps.

The total lumens required for any room is, then, the product of the desired intensity, in foot-candles, and the area of the surface to be illuminated, in square feet, divided by the coefficient of utilization. It should be remembered that the value for the desired intensity should be multiplied by a depreciation factor in order to ensure an average intensity in service equal to that originally chosen.

Location of Light Sources. From an analysis of distribution curves of the different units, fairly definite ratios of maximum spacing distance to hanging height which will insure a high degree of uniformity in illumination have been determined for various classes of reflecting equipment. Table XIV, with its foot-notes, presents values which may be used with the knowledge that if the ratios are not exceeded, uniformity of illumination will result. It may be emphasized at this point that *closer* spacings than those calculated may be used without hesitancy; uniformity of illumination will suffer only from too great a distance between units, never from too little. Although some of the units give a high degree of uniformity with wider spacings than those listed in the table, the long, heavy shadows which result from units widely separated

TABLE XIV

Maximum Spacings and Minimum Mounting Heights Recommended for Various Units

(Mounting height equals distance of light source above plane of illumination)

Equipment	*Ratio = $\frac{\text{Spacing}}{\text{Mounting Height}}$	†Ratio = $\frac{\text{Mounting Height}}{\text{Spacing}}$
Prismatic or mirrored glass		
Intensive	$1-\frac{1}{2}$	$\frac{2}{3}$
Focusing	$\frac{3}{4}$	$1-\frac{1}{3}$
Extensive	2	$\frac{1}{2}$
Indirect or semi-indirect	$1-\frac{1}{2}$‡	$\frac{2}{3}$‡
Opal or porcelain enamel: Bowl, Dome; Totally enclosing glass; Semi-enclosing	$1\frac{2}{3}$	$\frac{3}{5}$

* To get maximum spacing distance, multiply ratio by mounting height.
† To get minimum mounting height, multiply ratio by spacing distance.
‡ Height equals distance between ceiling and plane of illumination.

discourage the use of wide spacings in interior lighting. On the other hand, in some locations, as a restaurant, ball-room, or home, uniformity of illumination and absence of shadow are not only unnecessary but actually undesirable, and in such places "rules" are, of course, to be disregarded.

In many cases, the construction of a building divides it into a number of bays, and, for the sake of appearance, the units should usually be placed symmetrically in these bays if compatible with uniformity of illumination. Panel designs on the ceiling, or other decorative features, also call for a symmetrical spacing, but it must always fall within the limits of the table with regard to the height of the units above the working plane if uniformity is desired. When there are no natural divisions in the room, and the outlets are not already placed, the room should be divided into a number of areas approximately square, and the units placed at the center of each, the maximum distance between units falling within the limits of Table XIV. With such a location the distance from the nearest row of units to the wall is one-half the spacing distance; the distance of the units from the walls may sometimes, however, be made somewhat less than half the spacing distance in order to avoid shadows and to maintain a high intensity close to the walls.

The mounting height, it should be noted, is the vertical distance between the working plane and the lamp—not the distance between the floor and the lamp—except for indirect and semi-indirect systems, in which cases the height is the distance between the working plane and the ceiling, for with such units the ceiling acts as the light source. The use of a larger number of units than is required for the limiting spacing as previously mentioned does not detract from the uniformity of illumination; the considerations of higher costs for the equipment, as well as the arrangement and shape of the room, will usually be determining factors.

The distance at which totally indirect and semi-indirect units should be suspended from the ceiling is determined largely by considerations of appearance. The distance should not be so small that corners of the ceiling appear objectionably dark or should it be so great that much light is directed to the walls, or that a bright spot is formed beneath the unit. Between these limits variations in hanging height affect the efficiency only slightly.

Calculation of Illumination. After having determined upon the type of lighting unit to be used and the approximate location of outlets, the next step is to calculate the size of lamp required to produce the desired intensity of illumination. In some cases a choice of several arrangements of outlets is afforded, and here the problem is to determine which arrangement, in view of the lamps readily available, can best be employed to fulfill the requirements.

The lumens which the lamps must furnish initially are calculated by multiplying the area of the room to be lighted, in square feet, by the intensity desired for the particular purpose, multiplying this product by a depreciation factor as previously explained, and dividing the final product by the coefficient of utilization determined from consideration of the type of unit, the nature of the walls and ceiling, and the proportions of the room to be lighted. The number of lumens each lamp must give is then determined by dividing the total lumens by the number of lamps to be used. Expressing these relations in equation form we have

$$\text{Lumens per Outlet} = \frac{\text{Desired Foot-Candles} \times \text{Depreciation Factor} \times \text{Area in Sq. Ft.}}{\text{Coefficient of Utilization} \times \text{Number of Outlets}}$$

From Table XV, a type and size of lamp can be selected which will give the required number of lumens. In case the location of

TABLE XV

Generated Lumens

Mazda 110-Volt		Mazda 220-Volt		Mazda C-2 110-Volt		Mercury-Vapor	
Watts	Lumens	Watts	Lumens	Watts	Lumens	Size	Lumens
25 B	223	25 B	190			A.C.	
50 B	472	50 B	422			E	3179
75 C	865			75 C-2	600	F	6283
100 C	1260	100 B	900	100 C-2	870	D.C.	
150 C	2050			150 C-2	1400	H	2388
200 C	2920	200 C	2520	200 C-2	2000	HH	4712
300 C	4850	300 C	4100	300 C-2	3350	K	5529
400 C	6704	400 C	5850			L	3142
500 C	8725	500 C	7390	500 C-2	5600	P	6283
750 C	13860	750 C	12570			Z	18839
1000 C	19330	1000 C	17450				

outlets is closely limited by structural features, it will be necessary to make a choice between a size of lamp which will provide a lower intensity than that assumed as a basis for calculation and one which will provide a higher intensity. In such cases, the choice is not simply between a slightly higher expense than originally planned and a slightly lower one, but between a system which will prove adequate and one which may not; when it is considered how closely artificial lighting intensities approach the lower limit at which good vision is possible, it will be seen that the safest course is to employ the larger units. Where the number of outlets which can be employed advantageously is not so definitely fixed, a greater choice in the selection of a size of lamp exists, and no difficulty should be experienced in selecting a size which will provide an intensity approximating that originally assumed as a desirable value. Here again, when a choice must be made, a higher intensity than that originally assumed should receive the preference over a lower one. Table XVI shows the amount of white light reflected from different materials. The reflection factor of the surface worked upon greatly affects the foot-candle intensity required.

Table XVII has been prepared to show at a glance the important factors entering into illumination design. It may be mentioned that the order of operations can readily be varied to suit the requirements of individual problems. For example, if it

TABLE XVI

Relative Reflecting Power

Material	Per Cent
White blotting paper	82
White cartridge paper	80
Chrome yellow paper	62
Orange paper	50
Yellow wall paper	40
Light pink paper	36
Yellow cardboard	30
Light blue cardboard	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Blue-green paper	12
Black paper	5
Black cloth	1.2
Black velvet	.4

is desired to check the illumination intensity secured from a given system, the formula may be written in the form

$$\text{Foot-candles} = \frac{\text{Coefficient of Utilization} \times \text{Number of Outlets} \times \text{Lumens per Outlet}}{\text{Area in Square Feet} \times \text{Depreciation Factor}}$$

PROBLEM

It is desired to design a lighting installation for the erecting room of an industrial plant manufacturing large engine parts, cranes, etc. The work carried on in this room can be classed as assembly work, medium grade. The floor plan and end elevation are shown in Fig. 74.

The following data form the basis for calculations:

Length, 440 feet

Width, 95 feet

Distance from floor to crossbeam of roof truss, 44 feet

Distance from floor to top of crane, 39 feet

Color of walls and ceiling, medium

For a lighting installation of this kind, the units must either be mounted high in order to clear the traveling crane, or must be located on the side walls below the crane. The latter method of location would necessitate the use of angle reflectors which for a room of this size would not be desirable since it would be difficult to locate the light sources out of the normal range of vision and the

TABLE XVII

Chart of Important Factors in Illumination Design

Choice of System Page 96	Glare and reflected glare Shadow Illumination of vertical surfaces Color Wall brightness Efficiency Available units
Choice of Intensity Page 99	Nature of work Advertising value Table IV, page 32
Depreciation Factor Page 103	Depreciation of Lamp in service Depreciation of equipment and lamp due to collection of dust
Coefficient of Utilization Page 106	Light absorbed by reflecting equipment Light absorbed by ceiling and walls Size of room Table XI, page 100
Location of Outlets Page 108	Relation of spacing distance to hanging height Structural features of rooms or building Table XIV, page 109
Calculation of Lumens per Outlet Page 110	Lumens required per outlet = $\dfrac{\text{Foot-Candles} \times \text{Depreciation Factor} \times \text{Area in Sq. Ft.}}{\text{Coefficient of Utilization} \times \text{Number of Outlets}}$

glare would be very annoying. Locating the units high overhead will be found to be much more satisfactory, and, since most of the working materials have depolished surfaces, glaring reflections will

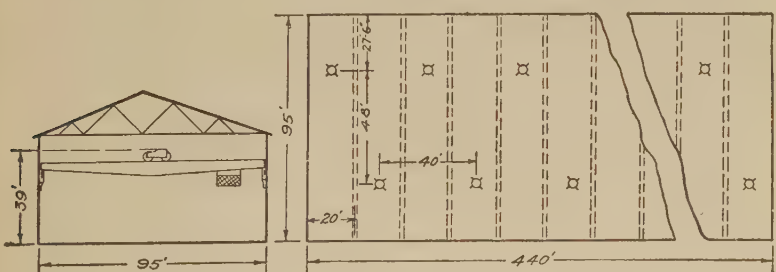


Fig. 74. Plan and Elevation of Machinery Assembling Room

not prove serious, consequently the dome-shaped, porcelain-enameled steel reflector and clear Mazda C lamp will supply a satisfactory quality of illumination.

Table XIV gives $1\frac{2}{3}$ as the maximum spacing ratio for dome-shaped steel reflectors. In this installation the hanging height of the units is somewhat limited because of the necessity of providing clearance for the traveling crane. The units must be suspended above the crane, preferably below the roof trusses. If the units are located about 1 foot below the crossbar of the roof truss, the hanging height above the working plane will be approximately 40 feet. The maximum allowable spacing would then be about 66 feet. Since the width of the room is 95 feet, the spacing provided when one row of units is used is in excess of that which is allowable. However, two rows of units should be sufficient. By using two rows and locating one unit between each three roof-truss crossbars, a 60-foot spacing is provided one way and approximately 48 feet the other way. Such an arrangement should prove satisfactory if the 14 units will supply sufficient light for the purpose at hand.

Table XII gives 3 to 9 foot-candles as satisfactory intensities for assembly work of medium grade. For this installation, an intensity of 4 foot-candles should be adequate. As there is very little smoke or steam in this room, the atmospheric conditions are not considered extreme. However, there is certain to be some dust collection on the lighting units, therefore the desirable intensity should be multiplied by a depreciation factor of 1.25 to insure that the average maintained intensity will not fall below the desired value. This gives an initial working intensity of 5 foot-candles. The coefficient of utilization for dome-shaped porcelain-enameled steel (RLM dome) reflectors for this particular room as calculated from the values given in Table XIII is found to be 0.50. The total generated lumens necessary to produce the initial intensity on the working plane are $\frac{4\times 1.25\times 95\times 440}{0.50}=418{,}000$ lumens.

Since 418,000 lumens must be supplied and the maximum number which can be supplied by the 1000-watt lamp is 19,300 (see Table XV), it is evident that 14 units will not be sufficient to supply the required amount of light. By using two rows of units and locating one between each two roof-truss crossbars, a 40-foot spacing is provided and the number of units required is 22. If 22 units are to be used, each lamp must supply $418{,}000 \div 22$ or 19,000 lumens, which is just slightly less than the number supplied by the 1000-

Fig. 75. Interior View of Assembling Room Lighted with Dome-Shaped Porcelain-Enameled Steel Reflectors and Clear Mazda C Lamps

TABLE XVIII

Analysis of Operating Costs—100- to 125-Volt Mazda Lamp Units*

Lamp and Reflector Data Upon Which Costs are Calculated													
Size of Lamp, Rated Watts	Mazda B 25	Mazda B 40	Mazda B 50	Mazda B 60	Mazda C 75	Mazda C 100	Mazda C 150	Mazda C 200	Mazda C 300	Mazda C 400	Mazda C 500	Mazda C 750	Mazda C 1000
†Cost of Lamp, List	$0.350	$0.350	$0.350	$0.400	$0.700	$1.100	$1.650	$2.200	$3.250	$4.300	$4.700	$6.500	$7.500
Cost of Lamp, Standard Package Discount	$0.315	$0.315	$0.315	$0.360	$0.630	$0.990	$1.485	$1.980	$2.925	$3.870	$4.230	$5.850	$6.750
Average Cost of Reflector with Socket, Standard Package Discount	$1.700	$1.700	$1.700	$1.700	$2.200	$2.300	$2.300	$3.200	$3.800	$3.800	$3.800	$4.900	$4.900
Cost of Unit, Standard Package Discount	$2.015	$2.015	$2.015	$2.060	$2.830	$3.290	$3.785	$5.180	$6.725	$7.670	$8.030	$10.750	$11.650
Operating Costs													
Annual Fixed Charges:													
Interest on Total Investment, 6%	$0.121	$0.121	$0.121	$0.124	$0.170	$0.197	$0.227	$0.311	$0.404	$0.460	$0.482	$0.645	$0.699
Depreciation on Reflector, 12½%	.213	.213	.213	.213	.275	.288	.288	.400	.475	.475	.475	.613	.613
Labor, Monthly Cleaning	.540	.540	.540	.540	.540	.540	.540	.810	.810	1.080	1.080	1.080	1.080
Total	$0.874	$0.874	$0.874	$0.877	$0.985	$1.025	$1.055	$1.521	$1.689	$2.015	$2.037	$2.338	$2.392
Maintenance Cost per 1000 Hours:													
Lamp Renewals, Standard Package Discount	$0.315	$0.315	$0.315	$0.360	$0.630	$0.990	$1.485	$1.980	$2.925	$3.870	$4.230	$5.850	$6.750
Lamp Renewals, $150 Contract Discount	.291	.291	.291	.332	.581	.913	1.370	1.826	2.698	3.569	3.901	5.395	6.225
Lamp Renewals, $1200 Contract Discount	.256	.256	.256	.292	.511	.803	1.205	1.606	2.373	3.139	3.431	4.745	5.475
Energy Cost per 1000 Hours at 1c per Kw-Hr.	$0.250	$0.400	$0.500	$0.600	$0.750	$1.000	$1.500	$2.000	$3.000	$4.000	$5.000	$7.500	$10.000

*The price of lamps and reflectors upon which calculations of this table are based are subject to change without notice; they are used here solely for convenience in engineering calculations.

†Discounts range from 10% to 40%, depending upon the quantity of lamps ordered.

TABLE XVIII — (Continued)

Total Annual Operating Costs — 110- to 125-Volt Mazda Lamp Units

Size of Lamp Rated Watts		Mazda B 25	Mazda B 40	Mazda B 50	Mazda B 60	Mazda C 75	Mazda C 100	Mazda C 150	Mazda C 200	Mazda C 300	Mazda C 400	Mazda C 500	Madza C 750	Madza C 1000
Energy at. . . . . 1000 hours operation per year. Lamps bought on $150 contract.	1c	$ 1.42	$ 1.57	$ 1.67	$ 1.81	$ 2.32	$ 2.94	$ 3.93	$ 5.35	$ 7.39	$ 9.58	$10.94	$15.23	$18.62
	2c	1.67	1.97	2.17	2.41	3.07	3.94	5.43	7.35	10.39	13.58	15.94	22.73	28.62
	3c	1.92	2.37	2.67	3.01	3.82	4.94	6.93	9.35	13.39	17.58	20.94	30.23	38.62
	4c	2.17	2.77	3.17	3.61	4.57	5.94	8.43	11.35	16.39	21.58	25.94	37.73	48.62
	5c	2.42	3.17	3.67	4.21	5.32	6.94	9.93	13.35	19.39	25.58	30.94	45.23	58.62
	6c	2.67	3.57	4.17	4.81	6.07	7.94	11.43	15.35	22.39	29.58	35.94	52.73	68.62
	8c	3.17	4.37	5.17	6.01	7.57	9.94	14.43	19.35	28.39	37.58	45.94	67.73	88.62
	10c	3.67	5.17	6.17	7.21	9.07	11.94	17.43	23.35	34.39	45.58	55.94	82.73	108.62
Energy at. . . . . 1000 hours operation per year. Lamps bought on $1200 contract.	1c	1.38	1.53	1.63	1.77	2.25	2.83	3.76	5.13	7.06	9.15	10.47	14.58	17.87
	2c	1.63	1.93	2.13	2.37	3.00	3.83	5.26	7.13	10.06	13.15	15.47	22.08	27.87
	3c	1.88	2.33	2.63	2.97	3.75	4.83	6.76	9.13	13.06	17.15	20.47	29.58	37.87
	4c	2.13	2.73	3.13	3.57	4.50	5.83	8.26	11.13	16.06	21.15	25.47	37.08	47.87
	5c	2.38	3.13	3.63	4.17	5.25	6.83	9.76	13.13	19.06	25.15	30.47	44.58	57.87
	6c	2.63	3.53	4.13	4.77	6.00	7.83	11.26	15.13	22.06	29.15	35.47	52.08	67.87
	8c	3.13	4.33	5.13	5.97	7.50	9.83	14.26	19.13	28.06	37.15	45.47	67.08	87.87
	10c	3.63	5.13	6.13	7.17	9.00	11.83	17.26	23.13	34.06	45.15	55.47	82.08	107.87
Energy at. . . . . 4000 hours operation per year. Lamps bought on $150 contract.	1c	3.04	3.64	4.04	4.61	6.31	8.68	12.54	16.83	24.48	32.29	37.64	53.92	67.29
	1½c	3.54	4.44	5.04	5.81	7.81	10.68	15.54	20.83	30.48	40.29	47.64	68.92	87.29
	2c	4.04	5.24	6.04	7.01	9.31	12.68	18.54	24.83	36.48	48.29	57.64	83.92	107.29
	3c	5.04	6.84	8.04	9.41	12.31	16.68	24.54	32.83	48.48	64.29	77.64	113.92	147.29
	4c	6.04	8.44	10.04	11.81	15.31	20.68	30.54	40.83	60.48	80.29	97.64	143.92	187.29
Energy at. . . . . 4000 hours operation per year. Lamps bought on $1200 contract.	1c	2.90	3.50	3.90	4.45	6.03	8.24	11.88	15.95	23.18	30.57	35.76	51.32	64.29
	1½c	3.40	4.30	4.90	5.65	7.53	10.24	14.88	19.95	29.18	38.57	45.76	66.32	84.29
	2c	3.90	5.10	5.90	6.85	9.03	12.24	17.88	23.95	35.18	46.57	55.76	81.32	104.29
	3c	4.90	6.70	7.90	9.25	12.03	16.24	23.88	31.95	47.18	62.57	75.76	111.32	114.29
	4c	5.90	8.30	9.90	11.65	15.03	20.24	29.88	39.95	59.18	78.57	95.76	141.32	134.29

watt clear Mazda C lamp. Fig. 75 shows the lighting installation as described in this problem, with the exception that in this case the units were staggered to decrease crane shadows and to improve the illumination at the ends of the building.

Estimating the Cost. In determining the total operating cost of any system of lighting, three items should be considered:

1. Fixed charges, which include interest on the investment, insurance and taxes, depreciation of permanent parts, regular attendance, and other expenses which are independent of the number of hours of use. Often this item forms a large part of the total operating expenses yet it is only too frequently omitted from cost tables.
2. Maintenance charges, which include renewal of parts, labor, and all costs, except the cost of energy, which depends upon the hours of burning.
3. The cost of energy, which depends upon the hours of burning and the rate charged.

If data are compiled under these heads in convenient units—for example, under the first head, an annual charge; under the second a charge per 1000 hours' operation; under the third a charge per 1000 hours' operation at unit cost of energy—the several items may easily be calculated for any given set of conditions and the total annual operating cost of any lighting system obtained as their sum.

Under fixed charges, the items of depreciation and attendance may be mentioned particularly. Depreciation should be charged on permanent parts only, and not upon parts the renewal of which is provided for in the maintenance cost. The rate for depreciation should in many cases be higher than the current practice, for obsolescence, rather than the wearing out of parts, determines the life of a lighting system. There are many installations in use today which are in good order and giving a fair measure of satisfaction, but which could be replaced at a large saving. In fact, there are no installations in this country which have been in use for seven or eight years that are not already obsolete.

Again, too much emphasis cannot be given to the desirability of regular attendance for those illuminants which do not require trimming from time to time. It is essential for satisfactory operation that such lamps and reflectors be cleaned at regular intervals, hence a fixed charge should always be included for this

service. Lamps, which require frequent trimming are cleaned at the same time, and the cost is included under the maintenance charge.

The energy cost can usually be readily computed, but will, in the case of some electric illuminants, depend upon the voltage of the circuit, since this determines either the wattage or the power-factor. The effect of power-factor is seldom considered although it governs the investment in generators, transformers, and wiring, and in a small degree the energy required. To the central station or isolated plant, the volt-amperes required by a given lamp are perhaps as close a measure of the cost of service as the actual wattage consumed. When the consumer is purchasing energy on a kilowatt-hour basis this factor, of course, is eliminated so far as he is concerned.

A table which would show the total operating expense of lamps of all sizes, with every discount from the list prices, for all possible periods of burning per year and under all costs of power, would be so large as to be entirely impractical. From Table XVIII, however, the operating expense of incandescent lamps under any set of conditions may be found with little calculation.

In the case of an incandescent system in addition to the wiring, the investment includes the cost of lamps, reflectors, holders, and sockets. The investment in permanent parts is the total investment minus the price of lamps. No depreciation is charged against the lamps inasmuch as they are regularly renewed. The labor item under fixed charges provides for the cleaning of all units once each month. For the smaller units with steel reflectors, the cost of cleaning in Table XVII is taken as $4\frac{1}{2}$ cents per unit for each cleaning. Data obtained from installations where accurate cost records are kept show that this figure is conservative for labor at 45 cents an hour. The cost of cleaning other reflectors is taken in proportion to the amount of labor required.

The maintenance charge is given for a 1000-hour period of burning. To find the annual charge in any case, it is necessary to multiply by the total hours of burning and to divide by 1000 hours.

The energy cost is given for a 1000-hour period, with energy at one cent per kilowatt-hour. The energy cost per year is found

by multiplying by the time of burning in thousands of hours and the rate in cents per kilowatt-hour.

An example will illustrate the use of Table XVIII. It is required to find the total operating expense per year for lighting the erecting room described on page 8. This room was lighted with 22 1000-watt Mazda C lamps. The lamps are burned a total of 4000 hours per year and are purchased at the discount obtained on a $1200 contract. The cost of energy is 2 cents per kilowatt-hour.

From the Table XVIII we obtain the following:

Fixed charges	$ 2.03
Maintenance 4.000×$5.475	21.90
Energy 4.000×2×$10	80.00
Total cost per unit	$ 103.93
Total cost for system	$2286.46

In Table XVIII are included annual operating costs which have been calculated for a number of cases frequently met in practice.

MODERN STREET LIGHTING, SHOWING LUMINOUS-ARC LAMPS ON A STREET IN UTICA, NEW YORK
Courtesy of General Electric Company

ELECTRIC LIGHTING

PART III

INTERIOR LIGHTING

OFFICES AND DRAFTING ROOMS

Nature of Problem. Today there is no reason for other than the best illumination in new office buildings and in the older offices, although in the latter case the result is attained at greater expense, for, in the majority of cases, some change in the location of outlets will be necessary. In general, however, the required alterations in wiring will be found profitable even where considerable expense is involved, *for there are no locations where the consequences of poor lighting are more serious or more keenly felt than in offices and drafting rooms.*

From the standpoint of utility, the problem of office lighting can be very simply stated. Fundamentally it is to provide the best illumination for sustained vision of flat surfaces in horizontal or slightly oblique planes in which papers, books, and photogaphs are usually examined. The perception of objects in their three dimensions, so important in the industries and in the arts, is here relatively unimportant. On the other hand, experience has shown that in offices and drafting rooms perhaps more than in any other locations, an ample intensity of soft well-diffused light must be provided in order that discomfort may be avoided and that the eyes may not become excessively fatigued by close application for long periods of time. There should be no extreme contrast in the brightness of objects within the field of view; shadows should be subdued, if not entirely avoided; the lighting system should be designed to permit flexibility in the arrangement of office furniture; it should be easy of maintenance and satisfactory in appearance.

In designing a system of office lighting, it should be remembered that standards of illumination intensity are rapidly and continuously rising as tenants and building managers come more and

more to appreciate the value of good illumination. Furthermore, allowance should be made for the fact that even in a small group of persons, one or more with defective eyesight will usually be found, and the lower limits of permissible intensity should not be approached so closely that unnecessary hardship is imposed on anyone. Again, it should be remembered that even where individual lamps are supplied for the illumination of the desks, a general illumination over the entire room of at least 1 foot-candle should also be provided.

In some buildings where careful attention has been given the design of the lighting in offices and hallways, an annoying drop in intensity is frequently apparent when one steps into an elevator. The adaptation of the eye is not instantaneous, and a person going from one intensity to another naturally moves slowly and with caution. Where, as in large modern offices, the time of a very large number of persons is dependent to a considerable extent on the elevator service, an ample intensity of lighting of the cars should be a first consideration.

Effect of Color on Quantity. The experience is not uncommon to those who occupy offices for which daylight furnishes illumination for the greater part of the time, that, as the natural light begins to fail and the lamps are switched on, the artificial illumination is seemingly inadequate—although at night the light is entirely satisfactory. This is due in part to the fact that the eye is, at this time of day, suffering from a certain degree of natural fatigue and in part to the disinclination of the eye to adapt itself to light of a lower intensity. Again, toward evening the horizon as seen through the windows is frequently even brighter than at midday and this, by contrast, makes the interior illumination seem even more inadequate. The difference in the color of artificial light and daylight also appears to be partially responsible for the same impression, and a combination of the two is displeasing to many. In such cases "daylight" lamps, which give illumination like sunlight in color, are desirable. These lamps are particularly serviceable where, as is often the case, artificial light is used in all working hours to supplement daylight in a room having insufficient window exposure. In fact, if such lamps are used in indirect fixtures, they will often pass unnoticed and thus

render productive an office for which it would otherwise be difficult to secure a satisfied tenant. Especially in office lighting, where the position of a light source with respect to the eye must remain practically without change for considerable periods of time, extreme contrasts, such as exist between the brilliant filament of a lamp in an open reflector and the general level of brightness of a room, may produce marked discomfort. Furthermore nine out of ten semi-indirect glass bowls now on the market are of too light density and are therefore unsatisfactory. Heavy density semi-indirect and totally indirect units not only overcome this objection, but at the same time minimize the specular reflection, or sheen, from books, paper, photographs, desk tops, etc., Fig. 76. In many cases desks are thoughtlessly given a high polish—not infrequently they are topped with plate glass—and in such cases the reflection of a source may approach in brilliancy that of the source itself. It is difficult to avoid reflections entirely, but the harmful effects can be minimized by employing only those units which are of low brilliancy, and by arranging them carefully with respect to the position of the desks, or vice versa. It is often possible, in the case of small offices where single desks are used, to arrange the desks along the wall so that those occupying the office have the light sources at their backs. In this way reflections from desk tops are prevented and the walls, unless highly finished or hung with pictures framed behind glass, will not give rise to objectionable reflections. Side walls of considerable area should not, it may be emphasized at this point, be finished so near to white that they will reflect a large volume of light into the eye nor should they be so dark as to cause undue contrast and needless absorption of light.

Shadow. Although shadows are very helpful in determining the shape and relative proportions of objects, they are not strictly necessary for the usual office where the work is largely with horizontal planes. In fact, an excess of shadow is likely to prove a decided nuisance; only enough to show the natural appearance of objects and persons is necessary. Dense shadows, such as those cast by a single unit of high intensity and relatively small size, or shadows with a series of sharp edges, such as cast by several small units, are particularly annoying. To be satisfactory from a

Fig. 76. Drafting Room Lighted with Heavy-Density Semi-Indirect Bowls

shadow standpoint, light sources should be of large area and low brilliancy, in order that such shadows as do form will be luminous and with gradually fading edges.

It is of particular importance in the case of drafting rooms that the light be highly diffused in order that shadows and reflected glare may be avoided. It will often be found more satisfactory from a lighting standpoint, and just as satisfactory from other standpoints, to work upon the dull side of tracing cloth rather than upon the shiny side.

From the data presented in the preceding paragraphs, and a careful review of Table XI, the following conclusions may be derived:

1. Open-reflector units are not suitable for large general offices from the standpoints of brightness, specular reflection, or shadow. A single direct-lighting unit, if of large area and low brilliancy, would be satisfactory for one person alone in an office when so located as to bring the light over the left shoulder. It should be designed to illuminate the surroundings to a fair intensity.

2. Semi-enclosing units are preferable to open-reflector units for office and drafting-room lighting. It is important that they be of large size and that the density of the glass bowl be such that they are satisfactory from a brightness standpoint.

Care must be used to place them so that specular reflection toward the eyes will be avoided as far as practicable. Semi-enclosing units are usually the best solution of the problem where it is actually impossible to obtain a light ceiling.

3. Semi-indirect units of light-density glass produce somewhat the same general lighting effect as direct-lighting units. Where the ceiling does not present a reasonably good reflecting surface and where it cannot be made into a good reflector, semi-enclosing units are, however, more efficient than light-density semi-indirect units and are equally good in most other respects. Where a ceiling of reasonably good reflecting power is obtainable, dense semi-indirect units are to be preferred. In other words, the legitimate field for light-density semi-indirect units as applied in office lighting is extremely limited.

4. Semi-indirect units of dense glass and totally indirect units are, in general, preferable to all others for office lighting where a ceiling of good reflecting power is obtainable. Brightness contrasts can be made entirely satisfactory, specular reflection is reduced to a minimum, and objectionable shadows are avoided. A lighting system of such units permits maximum flexibility in the arrangement of furniture in a general office and is usually the most practical system for a private office as well.

Obviously it is important that whether indirect, dense semi-indirect, or semi-enclosing units are selected, there should be no

unnecessary waste of light due to improper design. Whether the reflector is of mirrored-glass, opal, porcelain, or other material, it should be designed to permit easy cleaning, and should be hard and smooth in order that it may serve as a good reflector and be slow to accumulate dust; the contour should be such that light will not be pocketed and lost.

Location and Number of Lighting Units. In the case particularly of offices built for renting purposes, careful consideration should be given to locating the units in such a way that if partitions are later removed or new ones built in to suit the require-

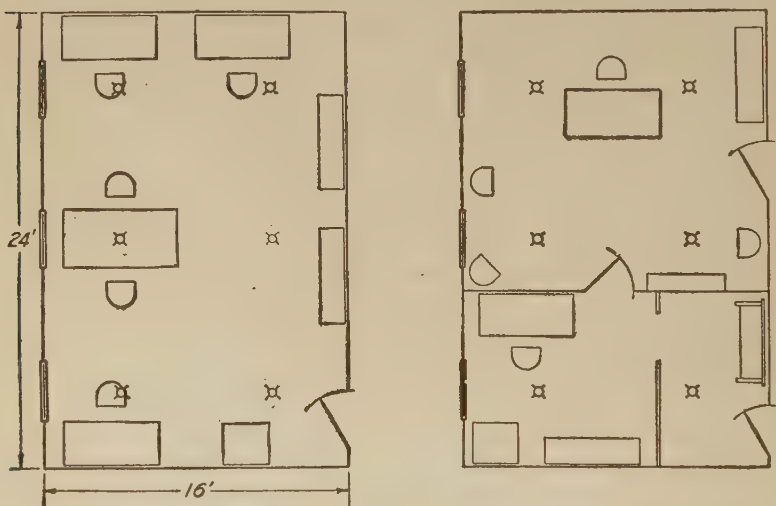


Fig. 77. Location of Outlets Should Provide for Possible Changes in Office Arrangement

ments of a tenant, the outlets already installed will still be usable. This factor alone is frequently of sufficient importance to justify the use of a greater number of outlets than necessary to suit the existing lighting requirements. Special structural features such as the location of ceiling beams and the placement of doors and windows should receive attention. The sketches of Fig. 77 illustrate how the use of 6 units in a room where 4 would satisfy conditions of uniformity, permits the change from a general office to a private one where, owing to the location of the windows, a change to two offices of equal size would be practically out of the question. The cost of installing, say, 6 units, need not necessarily

be much greater than that for 4, for the cost of glassware increases not in proportion to its diameter, but at a much faster rate, and the difference in its first cost may be sufficient to offset the greater cost of wiring. It is an advantage, too, if the number of different sizes of units and lamps employed in an office building can be kept small in order to facilitate replacement from stock. Sometimes it may be desirable to wire for locations where it is thought units may at some future time be desirable, but to seal the wires beneath the plaster until required.

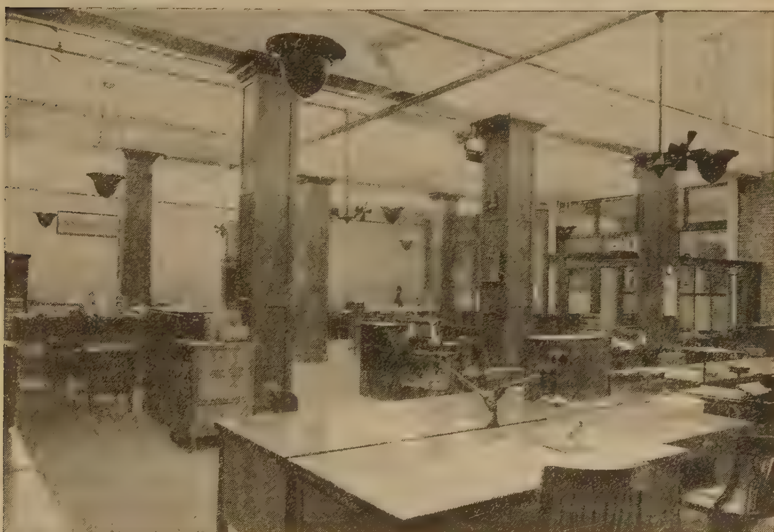


Fig. 78. Office Lighted with Indirect Units. Note Specular Reflection in Plate-Glass Desk Tops

Where totally indirect or dense semi-indirect units are used, and the greater part of the illumination comes from a large area on the ceiling, the question of direct glare is automatically cared for. On the other hand, because of the large ceiling area which is brightly lighted with such units, it is difficult to avoid a certain degree of specular reflection in polished surfaces, Fig. 78. Such reflection is not, of course, nearly so annoying as the image of a bright unit itself. Reflected glare from direct-lighting equipment can sometimes be avoided by arranging the desks along a

wall so that specularly reflected rays will travel away from the eye, rather than toward it, as shown in Fig. 79.

From a study of the light distribution of units with special reference to office lighting, it has been possible to establish fairly definite rules for determining the number of rows of units required, the spacing distance between units, and the distance from the walls to the nearest rows of units, to ensure a satisfactory illumination as regards both quantity and direction in all parts of the room. The data given in Table XIX have been applied very satisfactorily in practice.

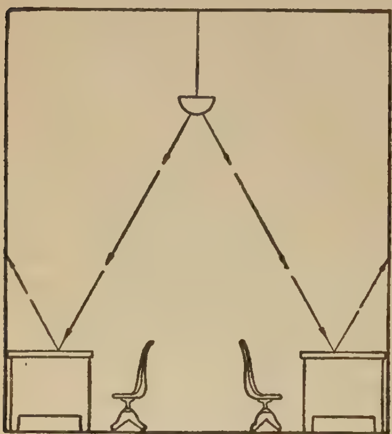


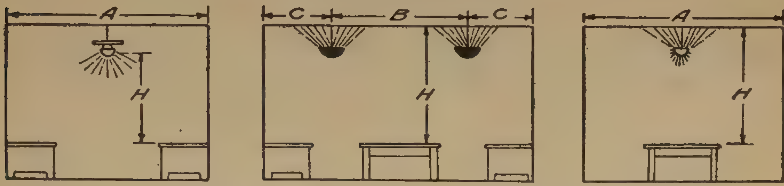
Fig. 79. Arrangement of Lights and Desks to Avoid Specular Reflection

Solution of Illustrative Problem. A lighting system is desired for a general office which measures 16 feet wide, 24 feet long, and has a ceiling height of 12 feet. The ceiling is light in color and the walls are of moderate reflecting power—a combination which is usually met in offices, and which permits the use of heavy-density semi-indirect or totally indirect units; for this office dense, semi-indirect units are selected. A beam running crosswise of the ceiling divides it into two bays which measure approximately 16 feet by 12 feet.

By reference to Table XIX, it is seen that two rows of units are required for an office 16 feet wide where the distance between the light source (the ceiling in the case of indirect units) and the working plane is $9\frac{1}{2}$ feet; if these rows consist of 2 units each, this office, 24 feet long, can be uniformly lighted. The units should not be located *more* than $5\frac{3}{4}$ feet from the walls; in this case they will be mounted 4 feet from the side walls and 8 feet apart, and about $5\frac{3}{4}$ feet from the end walls and $12\frac{1}{2}$ feet apart lengthwise of the office. The distance from the end walls might be varied slightly so as to locate the units along the center line of the bay. The units would be suspended at a distance of 2 to 3 feet below the ceiling and, if thought desirable, the lamps could be

TABLE XIX

Maximum Ratios of Spacing to Height of Light Source for Satisfactory Office Illumination



System	Limits for One Row of Units $\frac{A}{H}$	Limits for More Than One Row of Units $\frac{B}{H}$	$\frac{C}{H}$
Indirect*.	1.3	1.5	0.6
Dense Semi-Indirect*. . .	1.2	1.5	0.6
Direct Semi-Enclosing . .	1.1	1.4	0.5
Direct Dense Opal	1.1	1.4	0.5

* With indirect or semi-indirect the ceiling is considered the light source.

dipped in an etching solution to eliminate the shadows of the suspensions and the bowls upon the ceiling.

Six foot-candles is a desirable intensity to select as a working value in designing the illumination for a general office. This value multiplied by a depreciation factor of 1.2 gives an intensity of 7.2 foot-candles as a desirable initial value. By multiplying 384 square feet, the area of the office, by 7.2, the foot-candle intensity desired, it is found that 2765 lumens must be supplied to the illumination plane.

From Table XIII the coefficient of utilization for dense semi-indirect units in a room 16 feet square and 12 feet high having a light ceiling and medium walls is found by interpolation to be approximately 0.25; for such a room 24 feet square the coefficient is 0.31 with the same units. For a room 16 by 24 feet, then, the coefficient is 0.25 plus $\frac{1}{3}(0.31-0.25)$, or 0.27.

By dividing the lumens required on the working plane, 2765, by the coefficient of utilization, 0.27, the lumens which the lamps must give initially is obtained. This value is 10,250.

The four lamps required must generate, initially, 10,250 lumens. Each lamp must supply, then, 2560 lumens. By reference to Table XV, it is seen that the 200-watt Mazda C lamp, which has an output of 2920 lumens, most nearly supplies the required number, and this lamp is accordingly selected. If a light of daylight quality were desired, the 300-watt Mazda C-2 lamps would be specified.

PROBLEM

A large general office is 40 feet wide and 120 feet long and has a ceiling $10\frac{1}{2}$ feet high. The reflection factors are, ceiling 60 per cent and walls 40 per cent. There is a row of posts down the center of the room 15 feet apart. Beams having a drop of 10 inches extend across the ceiling of the room 15 feet apart and rest on the posts.

Make a complete lighting layout for this office; state the type of reflector to be used and show exactly where each unit should be located and its height above the floor. Following Table XVII give a good reason for your choice at each step of the problem.

SCHOOLS

General Requirements. The following discussion is abstracted from the Illuminating Engineering Society Code of Lighting for School Buildings, which is the standard work on this subject. Inasmuch as the general principles governing offices and drafting rooms apply equally well to schoolrooms the consideration of these general principles has been omitted.

There are 20,000,000 school children in the United States who are devoting several hours each day to study or to the performance of other work equally trying to the eyes. According to the available statistics nearly 10 per cent of the number of school children examined are found to have defective vision.

The severe requirements imposed upon children's eyes by modern educational methods create need for the best of working conditions. Among these conditions lighting is of first importance. Improper lighting causes eye-strain, resulting in functional disorders, near-sightedness, and other defects of the eyes.

Artificial Illumination. The desirable illumination to be provided and the minimum to be maintained are given in Table XX.

TABLE XX

Desirable and Minimum Illumination for Schools

(I. E. S. Code)

	Artificial Lighting Foot-Candles (Lumens per Square Foot) at the Work	
	Minimum	Ordinary Practice
Storage spaces	0.25	0.5– 1.0
Stairways, corridors	0.5	1.0– 2.5
Gymnasiums	1.0	2.0– 5.0
Rough shop work	1.25	2.0– 4.0
Auditoriums, assembly rooms	1.5	2.5– 4.0
Classrooms, study rooms, libraries, laboratories, blackboards	3.0	3.5– 6.0
Fine shop work	3.5	4.0– 8.0
Sewing and drafting rooms	5.0	6.0–12.0

Walls should have a moderate reflection factor; the preferred colors are light gray, light buff, dark cream, and light olive green. Ceilings and friezes should have a high reflection factor; the preferred colors are white and light cream. Walls, desk tops, and other woodwork should have a dull finish.

Glossy Surfaces and Eye-Strain. Glossy surfaces of paper, woodwork, desk tops, walls, and blackboards are likely to cause eye-strain because of specular or mirror-like reflections of images of light sources, especially when artificial light is used. Mat or dull-finish surfaces are recommended. It is to be noted that a high reflection factor does not necessarily imply a polished or glazed surface.

To minimize eye-strain it is recommended that unglazed paper and large plain type be used in school books.

Blackboards. Blackboards should be of minimum size, practicable, and should not be placed between windows. Their position should be carefully determined so as to eliminate the glare due to specular reflection of images of either artificial or natural light sources directly into the eyes of occupants of the room. The surface of blackboards should be as dull as possible and this dullness should be maintained.

Glare, due to specular reflection from blackboards, may be reduced or eliminated by lighting them by means of properly placed and well-shaded local artificial light sources.

In Fig. 80 are shown some simple graphical considerations of blackboard lighting. In *a* is shown a plan view of a room with windows on one side. Rays of light are indicated by *A*, *B*, and *C*

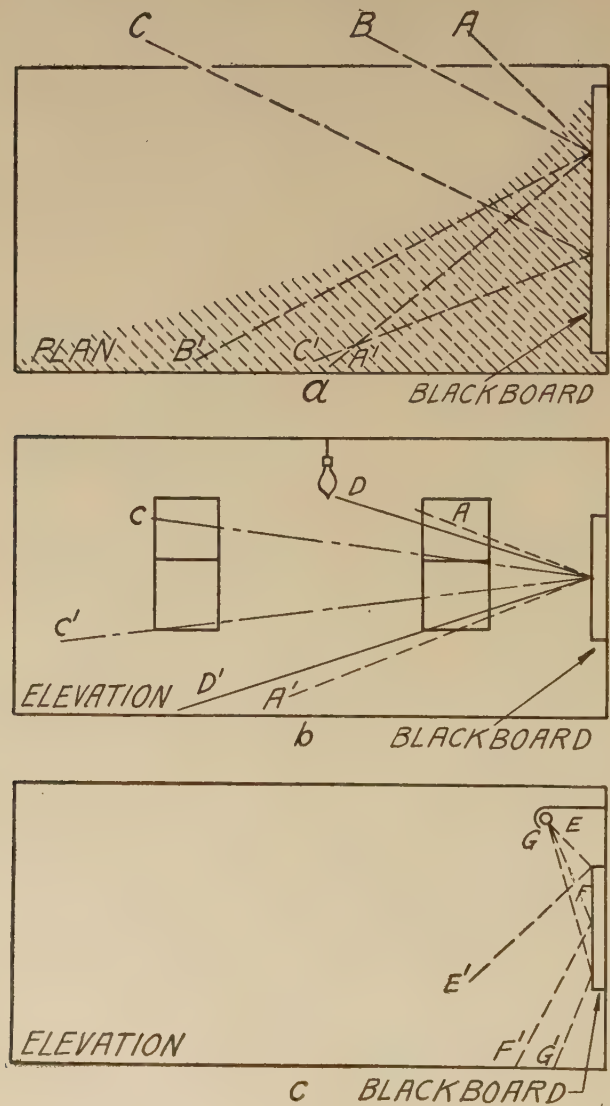


Fig. 80. *a*—Pupils in Shaded Area Are Subjected to Daylight Glare from Blackboards; *b*—Angles at Which Glare Is Experienced from Daylight and from Artificial Lighting to Minimize Glare; *c*—Proper Method of Lighting Blackboards

in a horizontal projection. These are supposed to come from a bright sky. By the application of the simple optical law of reflection—the angle of incidence is equal to the angle of reflection—it is seen that pupils seated in the shaded area will experience glare from the blackboards on the front wall. In *b* is shown the vertical projection of the foregoing condition. It will be apparent from this graphical illustration that by tilting the blackboard away from the wall at the top edge, the pupils in the back part of the room will be freed from the present glaring condition. Whether or not this tilting will remedy bad conditions may be readily determined in a given case. In *b* the effect of specular reflection of the image of an artificial light source is shown by *D*. In *c* is shown a proper method of lighting blackboards by means of

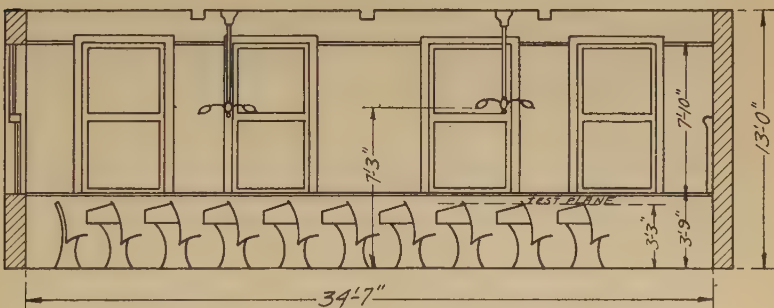


Fig. 81. Artificial Lighting Equipment Originally Installed in School Room

artificial lighting units. This will often remedy bad daylight conditions whether due to an insufficient illumination intensity of daylight or due to reflected images of a patch of sky.

In order to avoid excessive brightness contrast which is trying to the eyes, blackboards should not be placed on white or highly reflecting walls.

Rehabilitating the Lighting of Old Buildings. This will be illustrated by an actual case where the artificial lighting of a classroom was made satisfactory at a small expense. In Fig. 81 is shown an elevation of a section of the classroom showing the old fixtures. In Fig. 82 the circles containing crosses indicate the positions of the two old fixtures in this room. The chief objections to this old system were the following:

The lighting units were hung too low, so that eye-fatigue resulted from the bright sources in the visual field.

The light sources were not shielded from the pupils' eyes.

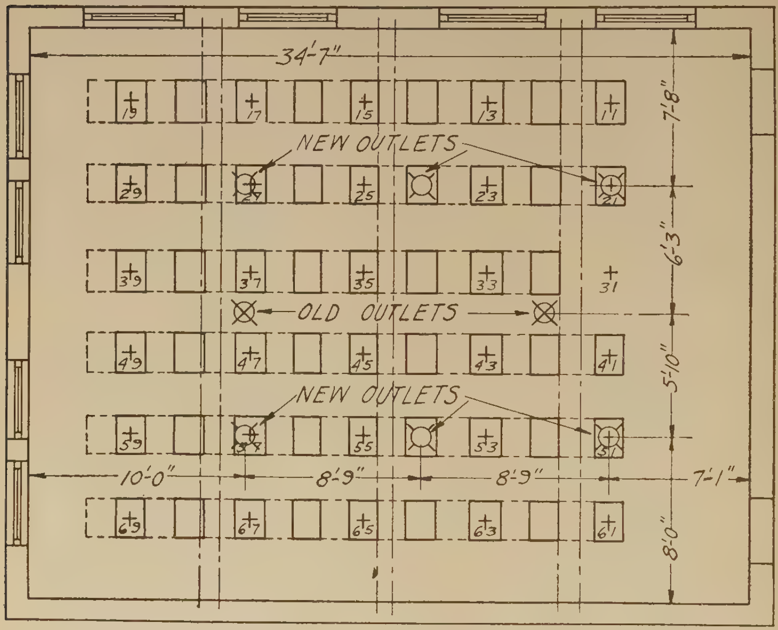


Fig. 82. Plan of Schoolroom Showing Old and New Lighting Outlets

Two fixtures are insufficient to provide satisfactory illumination over the entire work plane in a room of the dimensions shown. This unsatisfactory

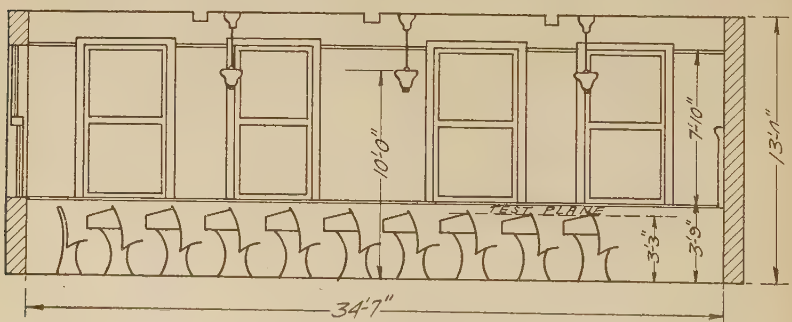


Fig. 83. Section Showing Location of New Lighting Outlets

condition was remedied by means of six fixtures placed as indicated by the circles (☒) in Fig. 82.

These fixtures, shown in elevation in Fig. 83, consisted of inverted diffusing glass shades containing one lamp each. The dimensions of the room are shown in the illustration.

STORES

Classification. For consideration of their lighting requirements, stores may be divided into four classes:

1. Department stores, and the large specialty stores of our principal cities
2. Medium-sized stores, including the large stores of the smaller cities
3. Small select stores and shops
4. Small stores of the usual type

In stores of the first-named class, the lighting requirements are very similar, although the location of stores, their size, and the individual preferences of their owners will, of course, cause considerable variation in the design of lighting installations. Such stores are usually imposing establishments and the lighting equipment should assist in furthering the impression created by the store as a whole. On the main floor, especially, a high intensity of light and a pleasing appearance of equipment are necessary.

For stores of medium size, in which class it will be noted are included the large stores of the smaller cities, the system provided should possess distinctive and decorative features, but these should be obtained with due regard to the efficient utilization of the light.

In the select small store or shop, great freedom is usually permissible in the selection of a lighting system; good appearance and a pleasing effect are the important considerations.

For the usual small store, elaborate lighting is not required; rather, the system should supply plenty of light efficiently.

Department and Large Specialty Stores. For the main floor of a department or large specialty store, a system of enclosing units or of some form of semi-indirect or totally indirect units is preferable to a system employing open reflectors, Fig. 84. The efficiency of the luminous-bowl unit on the right is but little impaired by the massive metal decorations, for the bowl supplies only a very small portion of the illumination. On the other hand, the same decorations applied to the semi-indirect or enclosing units illustrated would not only produce unpleasant contrasts but

would absorb a considerable portion of the light. With the exception of the prismatic type, totally enclosing units do not

Fig. 84. Decorative Designs Compatible with Good Engineering

provide a high degree of light control, and the maximum candle-power is usually in a direction near the horizontal. In order to

avoid undue glare, the units should be of large area and highly diffusive. A portion of the light from these units is transmitted directly to the objects beneath, and another portion reaches them by reflection from the ceiling, but the efficiency of an opal enclosing-unit system will not be materially higher than that of a good totally indirect system, except where the ceiling is finished in an unusually dark color; for with the opal units a large percentage of the light flux is emitted at angles near the horizontal and never reaches the counters. Light emitted near the horizontal does, however, serve a very useful purpose, in that it illuminates vertical or inclined surfaces, such as shelves, racks, etc., which, if lighted only from directly above, would be inadequately illuminated. Enclosing units are obtainable in a wide variety of shapes and sizes ranging from very inexpensive to very costly and exclusive designs, which features have led to their common use in all classes of stores.

Indirect Units. For comfortable vision, indirect and semi-indirect units are more desirable for the main floors of department stores than are enclosing units. With strictly indirect systems, where the ceiling acts as the light source and there is a pronounced downward direction to the light, the uniformity and diffusion of the illumination are excellent, glare from the light source is absent, and reflections from plate-glass and polished fixtures are avoided; however, shadows, which, if of the proper density, are a great aid in judging the shape and proportions of an object, may be too greatly reduced. The direction of the light, moreover, tends to make vertical surfaces appear poorly lighted. Since the illumination of the room is entirely dependent upon reflected light from the ceiling, the efficiency of the system will be highest if the ceiling is finished in white. However, with the present low cost of light, a tinted ceiling is justified where essential to the decorative scheme of the room or where lighting of a certain color tone is desired.

The luminous-bowl type of indirect unit produces the same general character of illumination as that produced by strictly indirect units, but the auxiliary bowl, being luminous, gives a direct component which assists slightly in illuminating vertical surfaces, and, in the opinion of many, adds to the decorative value of the installation.

Semi-Indirect Units. Semi-indirect units of dense or toned glass give an effect very similar to that given by luminous-bowl indirect units, but they transmit a higher percentage of the light, and are, under usual conditions, slightly more efficient. With bowls of light density, the results approach more nearly those obtained from opal-glass enclosing units; contrary to what might be expected, however, the semi-indirect system is often more efficient, owing to the fact that less light is absorbed by the bowl, less light is emitted in angles near the horizontal, and more light is directed to and diffused from the ceiling at effective angles.

It is possible to obtain either indirect or semi-indirect bowls in exclusive designs harmonizing with the decorations and conforming to the tastes of the user; regardless of the design of the exterior, however, it is of the utmost importance that the interior be a hard, smooth reflecting surface in order that good efficiency may be maintained. In an installation which runs into any considerable expenditure, it is well worth while to secure the opinion of a competent architect or decorator before determining upon a definite exterior design.

Upper-Floor Requirements. Lighting units of the general type mentioned are suitable for the upper floors of large stores; often a smaller size of the same design may be chosen. In some cases, a well-designed direct-lighting system may meet the requirements satisfactorily. With open reflectors, bowl-frosted lamps should always be installed and the units should be suspended at such a height that they will be, as nearly as possible, outside the ordinary range of vision. As previously stated, Mazda lamps of larger than 200 watts should not be used in open reflectors. Semi-enclosing units are available, however, which operate on much the same principle as an open reflector but which are provided with a diffusing glass bowl below the reflector which screens the lamp from view. With such units, any size of lamp may be used. Their efficiency compares favorably with that of the prismatic type of enclosing unit.

On all floors, the fixtures should be located symmetrically with respect to the divisions or bays usually formed in the ceiling by the constructional features of the building, unless it is desired to arrange the lighting to enhance some architectural effect in

light and shade, or color, in accordance with a skillful designer's well-considered plan.

Stores of Medium Size. The lighting requirements of stores of medium size are the same as those cited for large stores, except that a location amid less impressive surroundings may decrease the need for purely decorative features. In this class of store, a semi-indirect system employing some form of inexpensive medium-density bowl will often meet the requirements of a distinctive and economical installation. A well-designed direct-lighting system, such as might be used on the upper floors of large stores, is very frequently deemed entirely satisfactory, especially where a semi-enclosing unit is used.

Exclusive Stores. Exclusive small stores or shops, found principally in the larger cities, lend themselves to an artistic treatment which is impossible in larger areas. In many cases, the use of colored lamps to provide lighting of a distinctive tone is highly desirable, while uniformity of illumination is to be avoided rather than sought. The fixtures may well be of special design but care should be taken to avoid the very common error of allowing too brilliant light sources within the range of vision. Modifications of semi-indirect, indirect, and enclosing fixtures are used almost entirely.

Small Stores in General. Efficiency is the first requirement of a lighting system for the usual small store. A high intensity is necessary for the convenience of customers and for advertising purposes, but the fixtures may be of very simple design. Consequently, direct lighting with open reflectors, or with a good type of semi-enclosing unit, is, as a rule, most applicable although often the installation of an inexpensive semi-indirect or enclosing unit is preferable.

Semi-enclosing units possess an advantage over open reflectors in that they diffuse the light from the filament over a comparatively large area; hence they may be used with a lamp of any size, and in locations where open reflectors would cause annoying glare. They possess an advantage over opal enclosing units in that they distribute light in much the same way as a dense opal open reflector and are therefore less dependent for their efficiency upon the finish of the walls and ceiling.

A common mistake in small-store lighting is the installation of a single row of direct-lighting reflectors along the center of the store, where at least two rows of smaller units should be used to prevent the customer's shadow from interfering with his examination of the wares, and to illuminate the shelving or high cases along the side walls. A single row of semi-indirect or enclosing units is, however, usually satisfactory. An exception to the use of bowl-frosted lamps with open reflectors may be made in the case of small jewelry stores where brilliant reflections in gems and cut glass may be desirable; the units should, however, be placed well above the usual line of vision to avoid glare.

Illumination Intensities. A lighting installation serves a double purpose; first, it permits the merchandise to be examined with comfort; second, it advertises the store. Light is recognized as one of the least expensive and most effective of advertising mediums, and hence intensities higher than absolutely necessary for comfortable vision are almost universally demanded. The three factors which govern the selection of an intensity for any particular case are: the nature of the merchandise—for dark goods require a higher intensity than light goods to appear equally well illuminated; the illumination standard of the immediate neighborhood; and the amount which the owner feels it expedient to apportion for the advertising value of a high intensity. The lower values of any table of intensities should, therefore, be used cautiously and full weight given to local conditions. However, values applying to average conditions are useful as a basis upon which to estimate desirable intensities, and such values are given in Table XXI.

The maximum ratios of the spacing distance to the height of the unit above the working plane (not above the floor), which may be used with fair uniformity of illumination with the various types of units discussed, are given in Table XIV. If greater spacing distances than those determined by these ratios seem desirable, it should be remembered that as the spacing is increased the degree of uniformity decreases rapidly. The greater the permissible spacing distance, the larger the lamps which may be used and the fewer the number required. The fewer the units of a given type, the less the installation and operating expense, but

TABLE XXI

Range of Foot-Candle Intensities Desirable for Various Classes of Service

Department Stores and Large Specialty Stores	
Main Floors	6–10
Other Floors	4–8
Stores of Medium Size	
Book and Stationery	3–6
Clothing	4–8
Drug	4–8
Dry Goods	4–8
Furniture	3–6
Grocery	3–6
Exclusive Small Stores	
Light Goods	6–10
Dark Goods	8–12
Small Stores in General	
Art	5–8
Bake Shop	3–5
Book	3–5
Cigar	4–6
Clothing	4–8
Confectionery	3–5
Decorator	4–8
Drug	3–6
Dry Goods	4–8
Florist	3–5
Furrier	5–8
Grocery	3–5
Haberdashery	5–8
Hardware	3–4
Hat	4–6
Jewelry	4–6
Leather	4–6
Meat	3–5
Millinery	4–8
Music	3–5
Notions	3–5
Piano	3–6
Shoe	3–5
Tailor	4–8
Tobacco	3–5

the greater the area affected by the failure of a lamp and the denser the shadows.

Show=Windows. The ultimate purpose of a show-window is to create a desire to purchase. It may do this directly, by displaying objects which, when seen by an observer, are desired at once, or indirectly, by imparting to the observer a desire to inspect further the establishment of which the show-window is a part. A show-window usually appears as a picture in which the window-dresser has endeavored to portray one object or a group of objects in such a manner that the display has the power to draw and to hold the attention by appealing to the observer's sense of beauty or of the unusual. At night the degree to which this is accom-

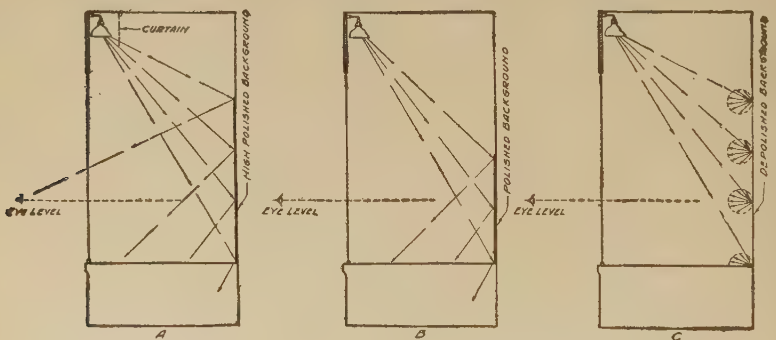


Fig. 85. Diagram Showing Effect of Window Backgrounds with Reference to Specular Reflection

plished depends not only upon the display itself, but also upon the manner in which it is illuminated.

As far as the amount of illumination in the window is concerned, the hanging height of the lamps makes little difference provided the proper reflector is chosen and the light sources are concealed; it is important, however, that the units be concealed, for a show-window should attract attention to the display rather than to the light sources. If the window glass does not extend all the way up to the ceiling, there may be room to mount the units along the top front edge so that they cannot be seen from the sidewalk. If conditions are otherwise, it may be necessary to drop a curtain or valance next to the glass for a foot or two from the ceiling. A translucent sign extending across the top of the

glass illuminated from behind by the lamps which light the window may be utilized in some cases to advantage.

Reflections of light sources from polished surfaces are sometimes of such brilliancy that they produce a blinding effect almost as extreme as would the light source itself. If a lamp is placed as shown at *a*, Fig. 85, in a window with a polished background, such as a mirror or a polished-wood paneling which extends almost from the floor of the window to the ceiling, the image of the source will be reflected into the eye of the observer, as shown by the broken lines. If the background does not extend up so high, as at *B*, little reflected light will strike the eye at its ordinary height. The same result can be secured by dropping a curtain between the light sources and a high background, as indicated at *A;* or, if the background is a necessary part of the display, it may be mat-finished so that the reflection, instead of forming a brilliant image, will be diffused in all directions, as shown at *C*. When light is reflected from mat surfaces in all directions, the whole surface appears uniformly illuminated and no excessively brilliant image is formed to dazzle the eye.

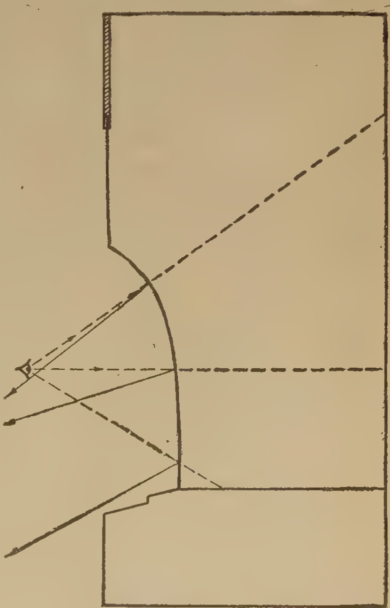


Fig. 86. Curved Window Glass Prevents Direct Reflections

Another source of annoyance to the observer of a show-window, either by day or by night, is the reflection in the window glass of bright objects on the street, or lights from nearby buildings and windows. In many instances this cannot be easily remedied. However, by the use of curved window glass, such as shown in Fig. 86, this condition of direct reflection can be avoided and the attractiveness of the show-window be preserved.

Light Direction. A certain degree of shadow is necessary in order that each part of an object may appear in its proper rela-

tion to every other part. If a window is illuminated in such a way that all shadow is avoided, the display is certain to appear flat. The importance of shadow in lighting is well illustrated by the photographs of Fig. 74. On the other hand, if the usual display were illuminated by a single large unit mounted at the ceiling near the glass, the contrast of light and shade might be too pronounced. It is well, therefore, to have available a greater number of smaller units employing, in most cases, the 100-watt Mazda C or 150-watt Mazda C-2 lamps mounted along the top front edge of the window. It is a great advantage to have installed two or three times as many outlets as are needed for any one form of lighting. These should be wired in groups so that the direction of the light can be varied to secure any degree of light and shade by merely operating the proper switches. In those cases of window lighting where striking effects of light and shade contrasts are desirable, advantage can be taken of this special construction and placing of units. For instance, a display may have a central figure which demands a more pronounced contrast of light and shade than could be secured with a uniform spacing of units. For such an effect, several units may be grouped as shown in Fig. 87. This arrangement of units gives the central figure its proper appearance, and at the same time prevents objectionable shadows on the remainder of the display. Again, the window trim may consist only of one object, requiring heavy shadow effects, and in such a case the display can often be best lighted by placing a single large lamp with a reflector in one of the upper front corners of the window.

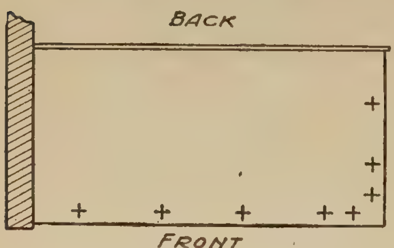


Fig. 87. Suggested Layout for Securing Highlights

Color variation is, perhaps, the most effective means of holding attention. A florist's window, for example, can be made to change wonderfully by simply changing the color quality of the light which illuminates it. If it is lighted entirely by a white light, such as is obtained with Mazda C-2 lamps, the whites, blues, greens, and violets will appear to stand out equally

with the reds, yellows, and browns with which they are contrasted. If the color quality of the light is made to change by adding to the white light warmer tones from amber-colored bulbs, the colors that first appeared prominent will appear to fade and the yellows and browns will be given prominence. Again, if red is added, the effect will be to make the contrasts between red and the other colors more marked. Such effects, as mentioned, may be readily secured if the window is provided with several circuits. The colors in rugs, dress goods, wall paper, pictures, paintings, etc., are susceptible to the same treatment. A window-dresser who makes a study of the possibilities of colored light as well as of light direction, will be able to produce beautiful and unusual effects.

Intensity. The light required to produce a suitable intensity for show-window lighting depends, among other things, upon the brightness of the street as a whole. A display which is located on a relatively dark side-street where other windows are unlighted will require less illumination than one which is located on a brightly lighted thoroughfare where the buildings and windows are also well illuminated. Further, objects are seen not by the light which strikes them but by the light which they reflect; hence, a window in which dark goods are displayed must be illuminated to several times the intensity of a window in which white goods are displayed to appear lighted to an equal intensity. A light-colored show-window display in a small town might be well lighted at an intensity of 10 foot-candles, a similar display on a prominent street in a city might profitably use 25 foot-candles, while for all dark display under the latter conditions, 50 foot-candles might well be employed. The range of intensities, then, which is suitable for show-window lighting may be given as 10 to 50 foot-candles, depending on the color of the display and the relative brightness of the window surroundings.

Owing to the fundamental difference in design and purpose between show-window and other interior-lighting installations, the ordinary method of calculating the power requirements for a given intensity of illumination cannot be employed. *Provided the proper type of reflector is chosen, for the problem in hand,* the following

formula is of sufficient accuracy for the great majority of window-lighting installations:

$$\text{Total watts required (Mazda C lamps)} = \frac{\text{ft.c.}(A+B)C}{5} \quad \text{(see Fig. 88).}$$

For example, if it is desired to illuminate a window to an intensity of 25 foot-candles and the dimensions are, height 9 feet, depth 7 feet, length 14 feet, the total wattage required is

$$\frac{25(10+7)14}{5} = 1190 \text{ watts.}$$

Twelve 100-watt Mazda C lamps or 12 150-watt Mazda C-2 lamps might be employed.

To obtain satisfactory results in a show-window more than in almost any other location it is necessary that a reflector giving the correct distribution of light be selected. Experience has shown that in general the most satisfactory and efficient equipment consists of individual reflectors of mirrored or prismatic glass. In each of these two types a variety of styles is available, so that the proper distribution of light for high, medium, low, and deep windows may be obtained.

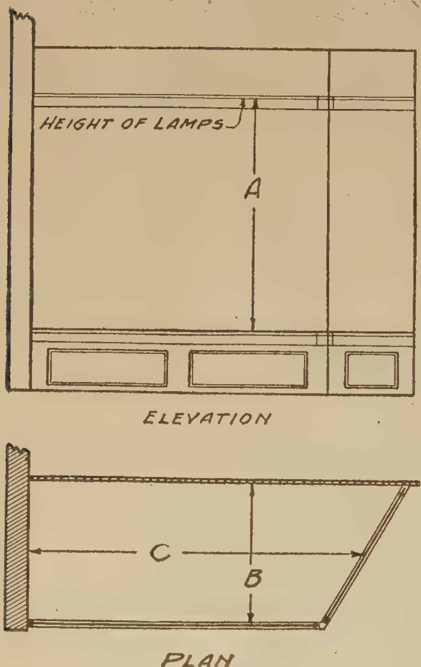


Fig. 88. Diagram of Show Window, with Important Dimensions

INDUSTRIAL PLANTS

Advantages of Proper Lighting. The proper illumination of our industrial establishments has become a matter of prime importance to the manufacturer, the workman, and the state. Only a few years ago the number of persons directly affected was small, for artificial lighting was largely a supplementary matter in

the factory; night operation was carried on in only a few industries, where the processes were of necessity continuous. It so happened that the visual requirements in these industries were not especially exacting. The press of war-time demands made multiple shifts necessary in all principal industries. Without night operation, much delay would have ensued while materials were secured, buildings erected, and machinery manufactured and installed. The power facilities of the country would have been entirely inadequate had they not been used by night as well as by day; more coal would have been consumed for a given production, and our national effort generally retarded. With peace-time adjustments made, most efficient production will likewise require the maximum use of capital expenditures for plant and equipment. Shorter hours of labor are an important factor, and it seems that at least two-shift operation, which would permit night sleep and daylight hours of recreation for all, will be adopted in an increasing number of industries.

Bad Existing Conditions. While our industrial success and efficiency have thus become dependent in important measure upon the artificial lighting facilities installed in our factories, the majority of these still have conditions of illumination that are a menace to the vision and general health of the operative, that create accident hazards, and that lead to spoilage of material and curtailment of output. The industrial commissions of various states are taking cognizance of these conditions and are formulating codes or regulations covering the lighting of industrial plants.

Fortunately, progress in the art of light production and application has been such that the new demands can be met with illumination of the requisite intensity, adequately controlled as regards direction, diffusion, and other desirable qualities. With modern lamps and accessories it is practicable and economical to furnish light of an intensity comparable with average daylight conditions in a factory and equal in quality, so that no harmful results can ensue and production can be kept at a maximum.

The advantages to the manufacturer of providing proper lighting facilities in his plant are nowhere better stated than in a bulletin on shop lighting issued to its members by the National Safety Council. From it the following paragraphs are quoted:

1. Without light and sight all manufacture ceases. Blindfold even the most skilled mechanic and he is helpless. Any piece of work which he attempted to do would surely be spoiled, and he would be liable to injure himself or some other workman.

2. Workmen in a poorly lighted factory are, in effect, partially blindfolded. The process of manufacturing goes on, but certainly not as efficiently as if adequate light were provided. Yet many manufacturers who supply their employes with the best of tools and equipment never consider the importance of the worker's eyes and the handicap of poor lighting. The efficiency of the workman determines the efficiency of the machine. Adequate illumination is probably the most essential factor in securing high efficiency of the workman.

3. Inadequate and improper illumination increases the probability of accidents. A careful analysis of 91,000 accidents showed that about twenty-four per cent were due wholly or in part to poor lighting.

4. While most employers and employes are familiar with the dangers to the eyes from mechanical injury, very few are aware of the harm done by poor lighting. Impairment of vision is a slow process, and it may take months and even years before the individual becomes aware of it. Fatigue and eye-strain, caused by improper lighting, will lead to near-sightedness, then to a gradual decrease of vision, and possibly to total blindness.

5. Good lighting is an investment, not an expenditure. In a plant which is properly illuminated accidents are less frequent, the employes work more efficiently and make fewer mistakes, a closer and better supervision of the men is possible, and the employes are better contented and more stable in employment because of the orderly and pleasant surroundings which are sure to result from good lighting.

Intensity. Today, work of every kind, including the most intricate operations and those requiring the utmost precision, must be carried on throughout the twenty-four hours. If artificial light could be had for the asking, no plant would be content with a lower standard of illumination by night than by day. For reference, Table XXII is given, which summarizes the values of daylight intensity, found in a large number of typical factories. Very properly, those operations requiring the closest scrutiny were found located nearest the windows and therefore received the highest intensity of illumination, as is shown by the first column of the table.

The minimum intensity to be supplied is that which will permit comfortable vision, conserve eyesight, and eliminate accident hazard. Many states, through their industrial commissions, are beginning to require the employer to make such minimum provision. Intensities for various classes of operations are specified, depending on the nature and fineness of the detail to be observed,

TABLE XXII

Working Intensities of Daylight Illumination in Foot-Candles

Factory Product	Grade of Work A	B	C
Engine lathes — Horizontal / Vertical, Min.-Max.	10 6 − 15	7 2 − 15	3 0.5 − 9
Automatic engine lathes	14 2 − 30	12 2 − 30	10 1 − 15
Machine forgings		6 2 − 15	5 1 − 10
Special machinery	10 4 − 20	7 3 − 15	
Lamps	10 5 − 16	9 1 − 15	
Vacuum cleaners	17 7 − 25	11 3 − 20	
Automobiles	5 2 − 11	5 2 − 8	5 3 − 11
Automobiles	10 6 − 12	3 1 − 3	5 4 − 5
Storage batteries		5 1 − 6	3 0.5 − 5
Machine tools and patterns	6 2 − 16	9 3 − 35	
Sheet iron equipment	10 1 − 20	5 1 − 12	8 2 − 15
Machine gears	7 3 − 16	8 5 − 18	5 1 − 15
Hardware	10 1 − 20	10 1 − 20	4 0.5 − 12
Printing machinery		5 1 − 15	3 0.5 − 5
Sewing machines		4 1 − 8	2 2 − 5
Cloth bags		5 3 − 10	7 3 − 10
Clothing	10 10 − 20	4 7 − 15	
Furniture	5 3 − 20	5 0.5 − 12	
Average	10 4 − 18	7 3 − 15	5 1.5 − 10

the closeness of application required, and the reflection factor of the working surfaces. These intensities are designed merely to protect the operative who must work for long hours under these conditions day after day.

Effect on Production. However, governmental requirements do not assure the most economical production, a factor of vital interest to the manufacturer, and to obtain which much higher intensity values are found necessary. It is difficult to recommend the exact intensity required in a given plant from the economic standpoint. This figure necessarily depends upon numerous factors such as the cost of producing light, the number and wages of the employes and the value of their output, all of which vary widely in different establishments. Again, the alertness and better

morale of the workmen in brightly lighted surroundings are at once reflected in the greater production of the plant.

There is a growing conviction that no one should be called upon to work continuously at any occupation under an intensity of less than 1 foot-candle regardless of how rough the operation may be. Table XII lists the present standards of intensity for different classes of work. There is no doubt that the use of higher values than are there listed will prove profitable in many cases. It is a notable fact, that in those factories in which the most study has been devoted to lighting, the highest intensities

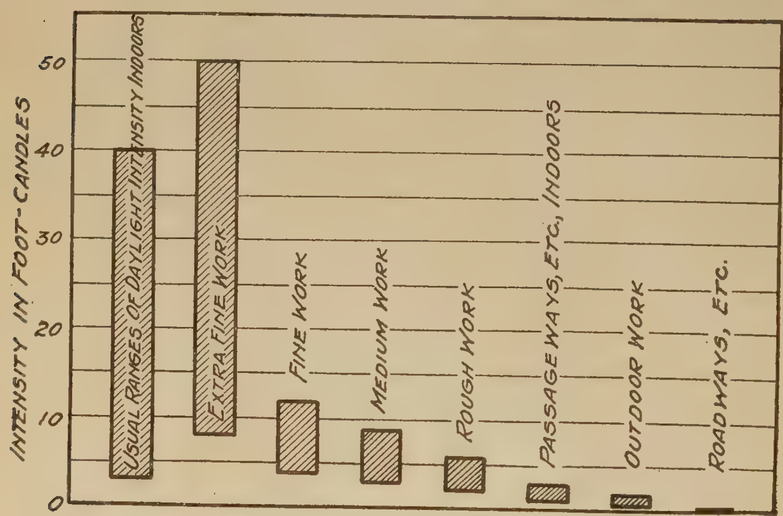


Fig. 89. Intensity Values Used in Industrial Lighting Compared with Usual Range of Daylight Intensities in Factory Interiors

have been adopted, based upon the experience that each increase has led to still more economical production.

Tests. Tests by Mr. W. A. Durgin in four Chicago plants where accurate cost and production records could be kept, showed that with intensities of the order of 10 to 12 foot-candles, the production increased from 10 to 35 per cent at a cost for lighting of only 1 to 5.5 per cent of the pay roll. These shops were engaged in various metal-machining and assembling operations and the previous lighting systems were, in one case, individual lamps on drop cords, and in the other three instances, modern

installations of general illumination ranging in intensity from 2 to 4 foot-candles.

The intensity values used in industrial lighting as compared with the usual range of daylight intensities existing in factory interiors are shown graphically in Fig. 89.

Necessity for Uniform Illumination. Moderate intensities of illumination in aisles and other intermediate spaces on the walls, etc., are necessary to safety, good vision, and a stimulating atmosphere. Light side walls are conducive to a cheerful impression of brightness throughout the room. Sources which direct considerable light to the vertical planes, and light wall colors, aid materially in accomplishing this.

The eyes of the workman looking up from his well-illuminated machine or bench are not adapted for vision at low intensities; hence, if adjacent objects and aisles are only dimly lighted, he will be compelled either to grope about, losing time and risking accident, or to wait until his eyes have become adapted to the low intensity. Glancing back at his work, he again loses time while the pupils of his eyes adjust themselves to the increased amount of light which reaches them. If long continued, this condition leads to fatigue as well as to interference with vision, and to accidents. The general illumination of all intermediate and surrounding areas should be sufficient to allow no marked contrast with the brightness of the working surfaces.

It is considerations such as these that have led to the almost universal adoption of the general or overhead system of lighting in modern industrial plants; they also constitute the strongest arguments for the use of translucent reflectors.

A purely local lighting system which provides light on the work only is not desirable. There are, however, instances in which an operation can be best illuminated by units located close to the work. Where this is the case, no general procedure for calculating the size and location of units can be formulated because of the wide range of conditions likely to be encountered. The general requirements for good illumination should, however, be followed. They necessitate the use of reflectors and lamps so located with respect to the work and the operator that the light source is shielded from his eyes and that excessive specular reflec-

tions in his direction may be avoided. Where local lighting is necessary there should be a moderate amount of general illumination in order that extreme contrasts between the intensity of light on the work and that on the surroundings may be obviated.

General Overhead Lighting. General overhead lighting has a very wide application in industrial work. The customary method is to divide the ceiling of the room into squares, or rectangles approximately square, and to locate one unit in the center of each. For some industries it may not be necessary to light each entire room to the same intensity. For instance, a large room may have a wide aisle running through the center with machine work on either side. The two sides may be considered as separate areas and lighted to a uniform intensity while the lighting units directly over the aisle may be of smaller size and spaced at greater distances. Again, there are certain industries where the locations of machines are symmetrical with respect to the room, or otherwise particularly located, and, if the operations at these machines are to be satisfactorily illuminated, the location of the overhead lighting units may well be modified to conform to the machine arrangement. A noteworthy instance of this is found in the textile industries, where looms, spinning frames, etc., are symmetrically arranged. When overhead units are located particularly with respect to these machines, there results a greater freedom from shadows on the working area. This arrangement is commonly known as modified general or group lighting. The advantage of the strictly symmetrical arrangement of units in contrast to group lighting is that the entire area of the room is uniformly illuminated, and, regardless of changes in the position of machines, an adequate intensity will be available. In modern factory practice a relocation of entire departments is not an uncommon occurrence.

In many machine shops and foundries, work-benches are located along the side walls. It is usually advisable to provide a row of lamps near enough to the walls to illuminate the benches satisfactorily. In many cases this may be accomplished simply by moving over the outside row of lamps in a purely general system one or two feet beyond its normal position with respect to the dimensions of the room, or, under other circumstances, an extra

row of smaller units at closer spacings and a lower mounting height may be found desirable.

In industrial lighting particularly is it desirable, for a given total wattage, to employ the least number of lighting units which will provide the best illumination. Not only is the expense for wiring and that for the cleaning of the units thus kept down, but the larger lamps are appreciably higher in efficiency. The problem is decided primarily by the minimum number necessary to provide reasonably uniform lighting, to supply light from a sufficient number of directions to illuminate adequately surfaces in all vertical planes, and to make the distance between units such that the light does not fall upon any working surface so obliquely as to make it likely that a person will stand in his own light. In general, with the units commonly employed in industrial lighting, an arrangement which provides reasonably uniform illumination will also provide satisfactory illumination of vertical surfaces and will obviate long, dense shadows.

Considerable Planning Necessary. Usually, a large room is divided by columns or ceiling beams into symmetrical bays. It is usually desirable that the units of a general lighting system be located symmetrically with respect to each bay and approximately in squares. Sometimes the proportions of interiors are such that a single outlet in the center of each bay will fill the requirements; again, the installation of four outlets per bay may be satisfactory; or, where long rectangular bays are found, two, three, or four units in a row may be desirable. Not infrequently, however, the proportions of the interior are such that the location of the least number of units to supply the required illumination calls for considerable planning in the design. Such a problem is presented by square bays measuring 20 feet on a side, and rectangular bays measuring 16 feet by 20 feet. The occurrence of these sizes in modern industrial plants is sufficiently common to warrant a somewhat detailed discussion of their lighting.

On a 20-foot spacing, dome reflectors should be mounted not less than 12 feet above the plane of the work. Ordinarily this calls for a minimum ceiling height of 16 feet. Hence, where bays 20 feet square are encountered, the use of a single unit per bay would not regularly be recommended unless the ceiling height

were 16 feet or more. On the other hand, four units per bay on a 10-foot spacing may be used where the ceiling height is not less than 10 feet, and their installation is good practice in all cases where it ranges between 10 and 16 feet. However, where the ceiling height is $12\frac{1}{2}$ feet or more, two dome-reflector units per bay, staggered as shown by the solid circles of Fig. 90, will answer the requirements at somewhat lower operating cost. Attention is called to the ease with which an extra unit may be

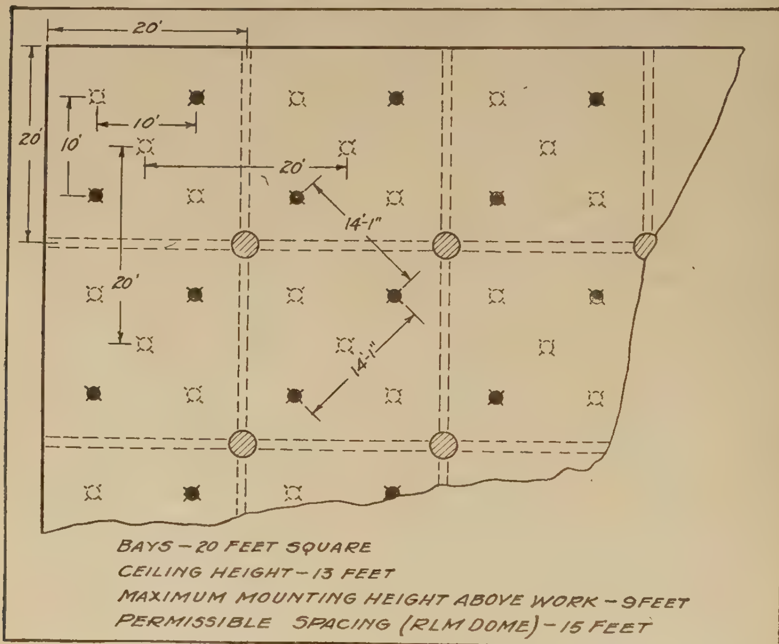


Fig. 90. Suggested Locations of Lighting Units for 20-Foot Bays with 13-Foot Ceilings

installed between every two units comprising the outside rows to provide an especially high intensity for bench work.

Where bays measuring 16 by 20 feet are found, one dome-type unit per bay will not provide uniform illumination unless a mounting height above the work of 12 feet, calling for a minimum ceiling height of 16 feet, is practical. Four units per bay are not necessary unless the ceiling height is less than $10\frac{1}{2}$ feet, and if less than 10 feet, six units are required. Between these ceiling heights, units mounted 10 feet 8 inches apart in the direction of the room crosswise of the bays and 10 feet apart lengthwise of the bays, as

shown in Fig. 91, provide uniform illumination at an average installation of three outlets per bay. This layout is particularly suitable where the number of bays in the room in a direction crosswise of the bays is odd, which brings a bay of four units at each end.

Adjust Spacing to Conditions. One factor always operates to encourage stretching the spacing ratio just a little—where a single unit per bay would barely exceed the permissible spacing.

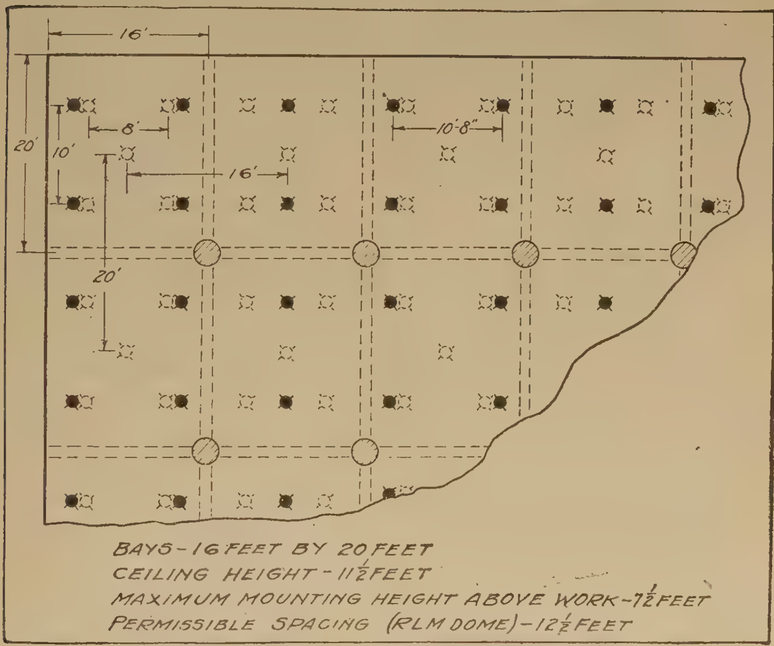


Fig. 91. Suggested Location of Lighting Units for 16- by 20-Foot Bays with 11½-Foot Ceilings

Under these conditions, it is well to remember that a single large Mazda C lamp supplies a full third more light than four smaller lamps totaling an equal wattage. While a spacing in excess of the maximum recommended will result in non-uniformity, nevertheless, if the ratio is not greater than two, the illumination supplied by the single large lamp will at the point of minimum intensity be practically equal to the illumination supplied by the four smaller lamps, and will, of course, be higher at all other

points, Fig. 92. However, it must be remembered when the spacing is being decided that the number of sources directing light to an object is reduced when the spacing is increased to such a ratio, and, too, that the light from the units reaches these objects more obliquely and forms more troublesome shadows. The use of a single large unit instead of four smaller ones is principally applicable in commercial lighting, but occasionally it offers the best solution of an industrial lighting problem; it is decidedly advantageous in all industrial lighting to avoid a spacing distance greater than twice the mounting height above the work plane.

Typical Case of Lighting Tool Shop. In Figs. 93 and 94 will be found a comparison of the lighting of a tool shop by means of 3-ampere, 220-volt D.C. enclosed arcs and 150-watt Mazda

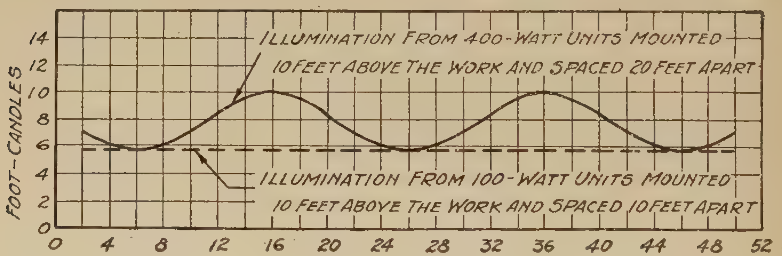


Fig. 92. Comparison of Lighting Systems

lamps, respectively. The same total wattage was installed in both systems. The arc installation was supplemented by about 50 carbon drop lamps over the machines, which were found to be unnecessary when the Mazda units were employed. It should be noted that in addition to producing a much higher average intensity of light, the distribution from the Mazda units is far more uniform; the intensity from the arc installation varied between 0.17 and 4.45 foot-candles at points which required equally good lighting. When the carbon drop lamps are omitted from the comparison, the data for these two installations are as given in Table XXIII. Figs. 87 and 88 also illustrate the usual method of finding the average intensity of illumination in a given room, by dividing a representative area between lamps into small squares and taking a measurement of the intensity of illumination at the center of each square.

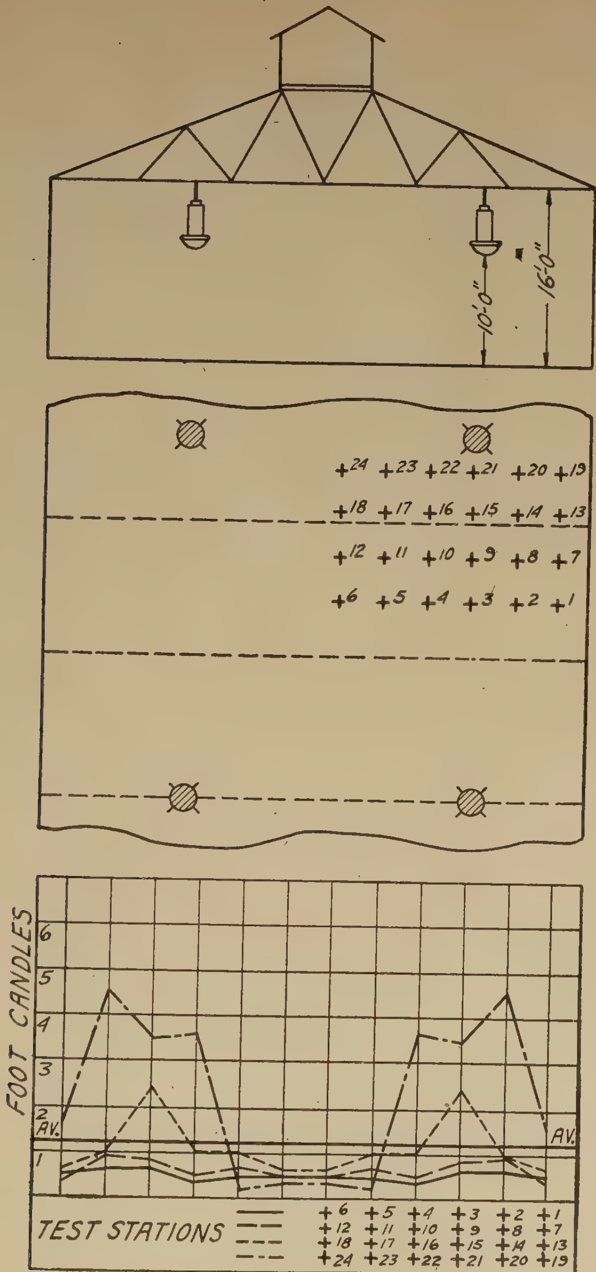


Fig. 93. Test of Efficiency of Enclosed-Arc Lamps in Tool Shop

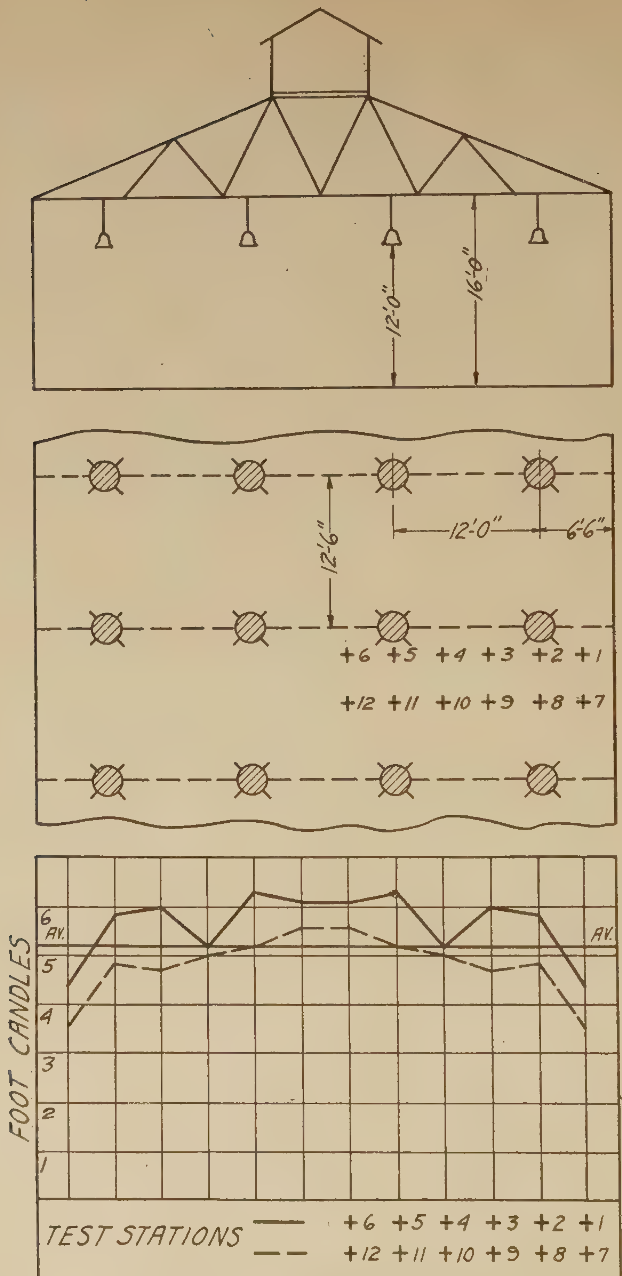


Fig. 94. Test of Efficiency of 150-Watt Mazda Lamps in Tool Factory

TABLE XXIII

Comparison of Arc and Mazda Lamps

	220-Volt Arc Lamps	110-Volt Mazda Lamps
Total number of lamps required	16	80
Height of lamps above floor, ft.	10	12.5
Height of test plane, ft.	3.5	3.5
Lamps per bay	1.25	4
Watts per lamp	750	150
Rated efficiency, w.p.c.	...	1.12
Area of bay (12.5′x49.5′), sq. ft.	618	618
Watts per sq. ft.	0.97	0.97
Average intensity, ft-cdls.	1.15	5.25
Effective lumens, per watt	1.18	5.40

PROBLEM

It is desired to light a large machine shop in which both bench work and machine work of medium grade are being done. In this case it is desired to have an illumination of good quality devoid of glare and sharp shadows. The following data are supplied:

Length, 320 feet.

Width, 100 feet.

Size of bays, 100 feet×20 feet.

Ceiling height (min.), 20 feet.

Glass side walls, reflection factor equivalent to that of dark walls.

Color of ceiling, light.

(The crossbars of the roof trusses are 18 feet above the floor, overhead shafting and pulleys are mostly above the crossbars.)

Solution

Ninety-six 300-watt reflecto-cap units, Fig. 95, 16×20 foot spacing, units hung 1 foot below crossbars, coefficient of utilization 0.46. Fig. 96 is a photograph of the actual installation.

In all industrial plants, lighting and power circuits should be separate. Not only are fluctuations in voltage caused by the starting of motors or by the sudden shifting of heavy loads thereby confined mainly to the power circuit, and their effect upon lamp performance thus reduced, but with this arrangement

trouble in the power circuit is far less likely to cut off the illumination of the plant at a moment when light is urgently needed.

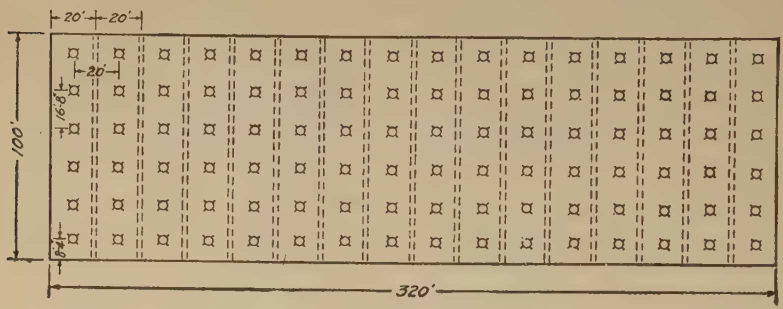


Fig. 95. Spacing of 96- to 300-Watt Reflecto-Cap Units in Machine Shop Shown in Fig. 96

RAILWAYS AND STREET CARS

Standard Arrangement. From the standpoint of illumination design a car interior does not differ from other interiors except for the fact that the location of chairs or seats is for the most part fixed, and therefore the direction of view of the passenger is known; in the case of a street car the situation is complicated by the fact that in order to give complete satisfaction the system must also provide good illumination for newspaper reading by those having seats when the aisles are crowded. For both railway and street cars it has been found, however, that a single row of lamps down the center of the car, when equipped with suitable reflecting devices, can be made to meet the requirements, and this arrangement is gradually becoming standard for both types of cars.

In the early applications of electricity to car lighting little thought was given to proper diffusion or direction of light, and the system was usually both inefficient and glaring. Too often it consisted of one or more rows of bare lamps placed close to a ceiling of very dark tone. Recently, however, there has been a commendable trend toward the use of bowl-shaped opal reflectors with frosted lamps, and of diffusing glass hemispheres, placed close to the ceiling. With both of these types the conditions of vision are far more comfortable, especially when the ceilings are painted light in color to reduce the contrast between the light source and

Fig. 96. Interior View in Machine Shop Shown in Plan in Fig. 95

its background. The hemispheres have an advantage over other units for car lighting in that they can be made practically dust tight.

Most steam-railway cars are now supplied direct current at 32 or 64 volts from axle-driven generators and storage batteries located on the car. A table of incandescent lamps of both the vacuum and gas-filled types now available for use on these voltages is given in Table III.

In the case of street cars the power is of course supplied at 550 to 600 volts and ordinarily lamps of the 110-volt class are operated in groups, five in a series. Under these circumstances vacuum lamps only can be used, for, when a lamp fails, the full voltage of the line is impressed across its terminals; with the gas-filled lamps serious arcing will usually follow—a condition which the vacuum in the other type of lamps prevents.

RESIDENCES

Esthetic Considerations. In the illumination of the home the decorative element predominates, but nevertheless to be satisfactory it must comply with the general rules for good lighting.

In living rooms the use of a central ceiling fixture has been the almost invariable rule and, from the standpoint of efficiency no better location could be found for the light source, yet with this arrangement the illumination of the room nearly always leaves something to be desired. Central fixtures whether of the direct, indirect, or semi-indirect type always illuminate a room uniformly; there are no areas in comparative shadow to form a resting place for the eye. The effort to create a more pleasing and homelike impression has resulted in the more extended use of table lamps and well-shaded wall brackets, for with these the lighting may be localized and the effect of light and shade may be obtained in any degree desired. In such installations, however, where the central fixture has been omitted entirely, complete satisfaction is often lacking because of the difficulty of adequately illuminating the entire room, should the occasion require. This difficulty can be obviated by the use of some of the newer forms of the table and floor lamps as illustrated in Figs. 97 and 98.

These lamps, in addition to the usual equipment of frosted bulbs beneath the shade, also contain a mirrored or translucent reflector pointing upward, with which it is possible to direct a powerful light toward the ceiling and then diffuse it throughout the whole room. With this form of indirect lighting, however, the objection which has been found to the use of central fixtures is largely overcome, for the lamp standard may be placed at any point desired and therefore the light in all parts of the room will not be of the same intensity. In planning the wiring for the living room, ample provision should be made to supply portable lamps of all types, but in addition it is well to carry the wiring to an outlet in the center of the ceiling, for changes in the lighting art may bring back the use of central fixtures once more.

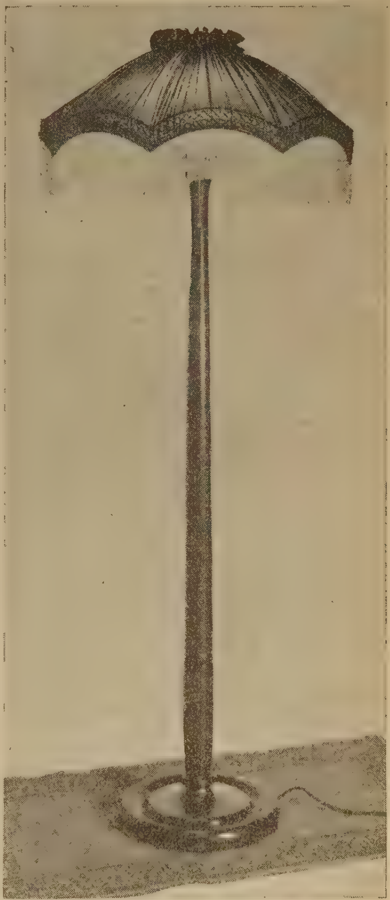


Fig. 97. Floor Lamp

The lighting requirements of the dining room are quite the opposite from those discussed above, for the arrangement of the furniture is entirely symmetrical with respect to the room, and in order to obtain satisfactory lighting, fixtures must nearly always be hung from the center of the ceiling. The choice of fixtures which will produce a pleasing illumination is, however, a matter which requires much thought. Although very popular, both semi-indirect bowls and chandeliers equipped with a number of unshaded round-bulb lamps should be avoided if really pleasing results are to be obtained. It should not be forgotten that the real purpose

of light is to provide a good illumination on the table and a soft light on the faces of those seated about it. In obtaining these effects, no type of fixture has ever excelled a well-designed dome suspended just high enough so as not to obstruct the view of the one seated across the table. With the dome, the table itself receives a high intensity of illumination direct from the lamps, but these lamps do not glare in the eyes of those seated around the table. Again, the comparatively low mounting height of the dome insures that light reaches the face largely in a horizontal direction, whereas with indirect fixtures or a cluster of lights mounted close to the ceiling the rays fall upon the face at a very oblique angle and thus tend to produce deep shadows around the eyes and the features. If it is thought that the use of the dome fixtures would not be in harmony with the furnishings of the room, the same effect may be secured by the use of a cluster of lamps hung low in very dense shades, or by equipping the table with well-shaded candelabra and providing soft general illumination of low intensity by means of wall brackets or a central fixture.

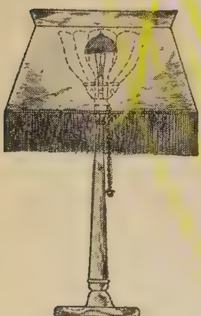


Fig. 98. Decorative Table Lamp Designed to Utilize Light Efficiently

As typical of a satisfactory and inexpensive lighting system for a small residence, Table XXIV is taken from a paper by Mr. A. L. Powell in the *Transactions* of the Illuminating Engineering Society.

Country-Home Equipments. The interest which has recently been shown in electric home lighting by means of small isolated plants is due no doubt in some measure to the success of similar but more complicated electric systems on automobiles.

The majority of country-home lighting outfits are supplied complete with gasoline, kerosene, or gas engine; generator; storage battery; and switchboard. The engine is usually an improved form of the type at present in extended use for driving pumps, operating washing machines, running churns, etc. Its operation is simple; it is rarely necessary to do more than supply fuel and oil as required. The speed of the engine is usually controlled by means of a simple governor which either reduces the supply of

TABLE XXIV

A Typical Residence Installation

Room	Number of Lights	Globe or Reflector	Remarks
Hall (front) 10′×4′ 6″	1 10-watt Mazda	Opalescent enclosing globe	Walls dark green, ceiling white Lamp 7′ above floor
Living room 13′×14′	1 60-watt Mazda 2 15-watt Mazda portable	Semi-indirect opalescent bowl	Walls dark green, ceiling white Lamp 7′-6″ above floor
Dining room	1 60-watt Mazda 3 15-watt Mazda	Dome with silk diffusing screen underneath Back of art-glass window	Lamp 4′-9″ from floor
Den 11′×10′	1 100-watt Mazda 1 25-watt desk lamp	Total indirect lighting fixture	Walls dark green, ceiling white Lamp 7′-3″ above floor
Pantry	1 15-watt Mazda	Semi-indirect, opalescent bowl	Walls buff, ceiling white
Hall (rear)	1 15-watt Mazda	Lamp frosted, opal shade	Lamp 7′-6″ above floor
Bathroom 9′×6′	1 25-watt Mazda 1 25-watt Mazda	Opalescent glass, bowl-shaped reflector Metal reflector	Bracket lamp 5′-6″ from floor Mounted at right of mirror
Bedroom 10′×14′	1 15-watt Mazda 1 40-watt Mazda	Cylindrical diffusing shade Deep bowl-shaped diffusing shade	Bracket lamp Ceiling lamp 7′-8″ above floor
Kitchen 9′×11′	1 40-watt Mazda	Extensive prismatic reflector	Lamp 7′-6″ from floor

fuel reaching the cylinder of the engine or causes the engine to miss explosions when the speed exceeds a certain value. The generator is, of course, nothing more than a direct-current electric machine, which, when driven at a constant speed by the engine, will supply electrical energy at a nearly constant voltage. When the engine is running, lamps, small motors, or other appliances receive their current direct from the generator, and if more energy is generated than is required by the appliances the surplus is

stored in the battery for future use. When the engine is not running, the energy which has been stored in the battery is available, and there is no interruption of service. The switchboard usually carries an ammeter, which indicates the current flowing to or from the battery; a voltmeter, which shows at what electrical pressure current is being distributed to the various appliances; such switches and controlling devices as are necessary to the proper operation of the plant; and sometimes an ampere-hour meter which gives some indication of the amount of energy stored in the battery for future needs. For satisfactory service the storage battery naturally requires the same care that is given it on an automobile.

Capacity of Plant. In size, country-home lighting outfits range from about 500 watts upwards. For the usual home consisting of seven or eight rooms, with bathroom, attic, and basement, a plant with a generator capacity of 750 watts will provide ample energy for lighting the house and outbuildings, and will permit the use of an electric iron, small motors, or a toaster during the daytime when the lighting system is not in use or when not more than a few lights are used. Although a plant of smaller capacity would under usual conditions provide capacity sufficient for lighting alone, a size at least no smaller than 750 watts should be selected, because, with a smaller plant, electric irons and similar devices cannot be used to the best advantage. In general, the capacity of the plant should be equal to the total wattage of the lamps which are likely to be in use at any one time, but in no case should be less than 750 watts.

The problem of wiring the home for service from a small isolated plant is different from that of wiring one for service from a central-station circuit only in the respect that, in the former case, lamps and appliances require a high current at a low voltage, whereas in the latter they require high voltage and low current. While a house wired for 110-volt service may need some changes in wiring before the country-home lighting outfit is connected to the wires, an installation made for 28- to 32-volt operation and insulated to the 110- to 120-volt standard specification, will be ready for connection to any line which may come through the country in the future. Only the lamps and the electrical appliances

themselves need be changed. The converse would not in general be true for the reason that the lower voltage could not force sufficient current through the system to cause the connected apparatus to operate efficiently, and furthermore the energy taken, in forcing current through, is lost. Country-home lighting plants usually generate energy at 28 to 32 volts pressure, and a lamp, flatiron, or other device designed to operate at 28 to 32 volts requires four times the current that apparatus taking the same power but designed to operate on 120 volts pressure requires. If a country home were wired for 110-volt service and later for some reason a 28- to 32-volt isolated plant were installed and connected, and 28- to 30-volt lamps and appliances used, the inadequacy of the wiring would be most apparent in those circuits where electric iron, toaster, or other heating appliances high in wattage were connected, for the wires through which such appliances were supplied could not furnish them with the heavy current which they require, with the result that they would be slow to heat and might possibly never get hot enough for use. In the same way, the circuits supplying current to incandescent lamps would be forced to carry a heavier current than they were designed to carry, but if the circuits were short and the power required by the lamps were small, the lamps would operate satisfactorily. However, if several lamps were connected to a single circuit of considerable length, the decrease in their brilliancy might be very marked. No. 14 wire, which is the size commonly used for 110-volt lighting-circuit wiring, is satisfactory for a considerable part of a 28- to 32-volt installation, but special circuits should be provided for all devices consuming over 300 watts, for circuits which must carry the total current for small individual loads aggregating over 300 watts, and even for small loads at a great distance from the plant.

Use of Chart to Derive Light Specifications. Proper wire sizes for various loads, in watts, and lengths of copper wire, in feet, for a voltage drop within desirable limits is shown in Fig. 99. To use the chart, the actual length of wire which is needed, in feet, and the maximum load, in watts, must be known. The wire length includes both wires between the two points connected for each circuit. For example, 225 feet of wire is needed to connect a load of 280 watts to a supply approximately 110 feet dis-

tant. By following an imaginary 280-watt line horizontally across until the vertical line corresponding to 225 feet is reached,

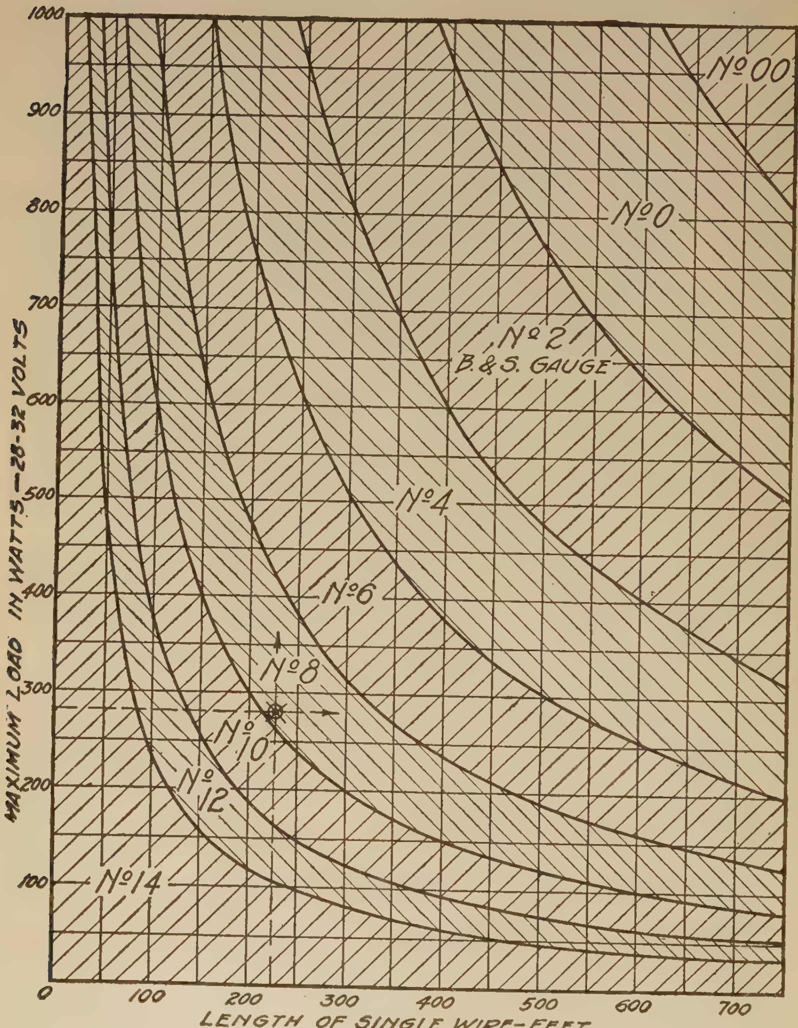


Fig 99. Chart for Obtaining Copper Wire Size (B.& S. Gage) for 28- to 32-Volt Circuits. Wire Length To Be Used Is Twice Wiring Distance between Points

as indicated on the table by the fine arrows, the point of intersection is found to lie in the area representing a wire size of No. 8, and wire of this size may be used.

The chart may be used to find the wire size for larger wattages or greater lengths of wire than those given directly on the chart. The method is simple: the number of watts is multiplied by the number of feet, giving a product which, for the sake of convenience, may be termed "watts-feet"; now two numbers are found on the chart which when multiplied together will equal the "watts-feet"; the wire size is then found by reading the intersection of the imaginary lines corresponding to the two numbers on the chart. For example, it is desired to find the wire size for a load of 1750 watts at a distance of 20 feet, which requires at least 40 feet of wire. The "watts-feet" value equals 1750 x 40, or 70,000. There are several combinations of numbers whose product equals the "watts-feet"—200 watts–350 feet; 350 watts–200 feet; 700 watts–100 feet; 500 watts–140 feet. By reference to the chart it is found that No. 8 wire fulfills the requirements for any one of these conditions, and this size should be used for a 1750-watt load carried 20 feet.

It is impossible, within the limits of this text book, to discuss the lighting of libraries, churches, theatres, government buildings, and other monumental structures. However, the same underlying principles apply as in the case of the simpler and more usual problems that have already been discussed. The proper lighting of important public buildings requires a combination of these principles with a treatment which is artistically correct, a result which can only be attained by long study and experience. For detailed descriptions of such installations the reader is referred to the *Transactions of the Illuminating Engineering Society.*

PROBLEM

State (*a*) the intensity of illumination, (*b*) the kind of lamp, and (*c*) the type of reflecting equipment which you would recommend for the following:

1. A small office with a dark-beamed ceiling
2. A high-grade haberdashery
3. A classroom in a grammar school
4. A cabinet-making shop
5. A large foundry having a width of 50 feet and height to the crane of 80 feet

EXTERIOR LIGHTING

FLOOD LIGHTING

Development of System. The appearance of structures brilliantly illuminated at night from an invisible source has always strongly attracted the popular mind. On special occasions, public buildings, monuments, etc., were many years ago lighted by means of arc searchlights; but inasmuch as such lamps require constant attention, the application of flood lighting of this kind was narrowly limited. The advent of the coiled-filament incandescent lamp in 1914 made available a point source of light of a character better suited to permanent installations, and since that time the use of flood lighting has increased with great rapidity.

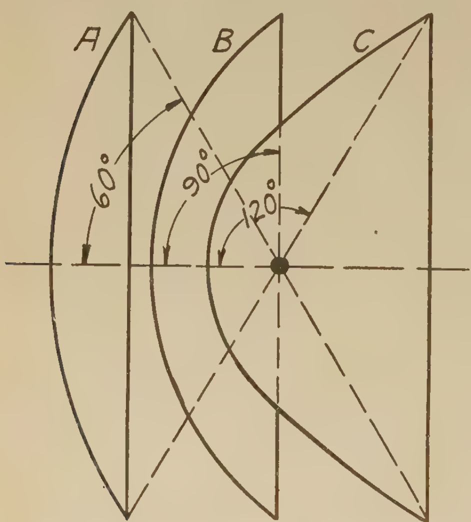


Fig. 100. Parabolic Reflectors of Varying Focal Length

Projectors. Projectors for incandescent lamps are of two classes. First, those designed to give a very narrow spread of light of the utmost beam intensity; i.e., searchlights. Second, those intended to give a somewhat broader spread and to include in this beam the largest proportion possible of the total light flux produced by the lamp. For searchlights a parabola having a comparatively long focus is found to give most satisfactory results, although only about one-sixth of the total light from the lamp may be incident upon the reflecting surface, and thence projected into the beam. The reason for this relatively low efficiency lies in the fact that the beam candle-power produced by a parabola with a given light source at its focus is dependent simply upon the candle-power of the source and the area of the reflecting surface; i.e., all the projectors shown in Fig. 100 will theoretically produce the same end-on candle-power when the light source is spherical.

With the flatter—that is, longer focus—parabola, differences between theoretical and actual candle-power measurements, due to error in contour, size of light source, etc., will be minimized; and therefore this contour would ordinarily be chosen for a searchlight. From the standpoint of reflecting a large volume of flux in the general direction desired, the deeper reflector, that is, one of short focus for a given diameter, is most effective, and a deep reflector should always be selected if a narrow beam is not essential; light which does not strike the reflector can scarcely enter the beam. Incandescent projectors range from 10,000 to 300,000 beam candle-power.

When considerable spread of light has been desired the practice has often been followed of putting the lamp out of focus until a hole appears in the beam, as is frequently seen in the case of the automobile headlight. Generally, however, a smoother beam will be secured if the contour of the projector is made to depart sufficiently from that of a true parabola to produce the distribution desired without having to put the lamp out of focus.

Projection Surfaces Used. There are three surfaces generally employed for light projection with incandescent lamps:

1. Silver, coefficient of reflection approximately 85 per cent.
2. Polished aluminum, coefficient of reflection approximately 62 per cent.
3. Nickel plate, coefficient of reflection approximately 65 per cent.

Silver plate may be applied directly to a metal surface, or may be deposited on a glass plane and then backed with a suitable protective coating. The silvered-glass mirror has a decided advantage over all other types in that it does not deteriorate when exposed to the atmosphere. However, care must be taken to secure a backing which will successfully withstand the temperature when used with a high-wattage incandescent lamp.

Silvered metal deteriorates rapidly when air circulates over it, particularly when salt or fumes are present. Nickel and aluminum are affected less rapidly than silver, and aluminum has the added advantage that it can be repolished without replating. Nevertheless, this initial efficiency is low and for all except temporary installations of flood lighting, mirrored-glass reflectors should be chosen. On the other hand, for low-wattage lamps, tightly enclosed in automobile headlights, silver-plated metal reflectors have been found generally satisfactory.

In locating and installing a flood-lighting installation thought must not only be given to the effect which will be produced the first night that the lamps are turned on, but also to means of ensuring that the installation will be maintained at a high standard of efficiency. Carefully designed projectors of good mechanical construction, Fig. 101, should be selected and the units should be mounted in such a way that they may be conveniently cleaned and re-lamped. If these considerations are not given due weight the installation will soon deteriorate to such a point that it might better be turned off entirely.

Rules for Installation. Only general rules can be given for installations of flood lighting. The structure chosen should be of

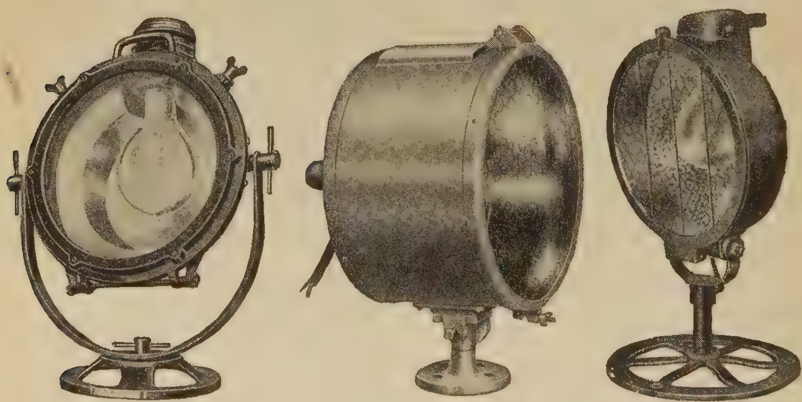


Fig. 101. Projectors for Flood Lighting

good architecture; that is, one which can afford to have its outlines thrown into bold relief, and the location of units must be such as not to distort these outlines. Buildings are planned for a satisfactory appearance under daylight conditions, at which time most of the light comes from above. It is usually desirable that artificial light should come from the same direction. Many installations have been successful in which the main battery of projectors has been located at one point and a secondary group so placed that their beams tend to lighten the shadows cast by the first without obliterating them.

The intensity of light to be supplied must be governed by the reflection factor of the material and the general brightness of the

surroundings. Most installations fall within a range of from 2 to 20 foot-candles, which corresponds roughly to $\frac{1}{3}$ to 5 watts per square foot for Mazda C lamps. The number of projectors should usually be such as to insure that two or more units bear on every point; this will prevent the appearance of a black spot when one lamp burns out, and will also tend to give the illuminated surface a smoother and more pleasing appearance under all conditions.

INDUSTRIAL PLANT LIGHTING

Lighting Requirements. Exterior lighting of industrial properties is required principally for the following purposes:

1. The illumination of yard thoroughfares, approaches, and passageways.
2. The identification and handling of materials stored out of doors.
3. The protection of buildings and materials against incendiarism, explosion, sabotage, and theft.
4. The guarding of the plant boundaries to exclude unauthorized persons.

Safety demands that any area which an employe is required to traverse after dark be lighted adequately. Owing to insufficient attention to these spaces in the past, the accident toll has been exceedingly high as compared with other parts of the plant used for corresponding periods. The requirements are more severe than in the usual street lighting, inasmuch as in emerging from a brightly lighted building or passing to another the eye does not quickly accommodate itself to the greatly diminished intensity. Fig. 89 indicates the range of lighting intensity, 0.05 to 0.25 foot-candles, usually found desirable for the yard thoroughfares.

To facilitate the handling of material in a yard with safety and expedition, the matter of shadows must receive careful attention; where material is stored in high piles satisfactory lighting becomes difficult. The illuminants should therefore be mounted high or a number employed to light a given space from several directions. When night work is carried on regularly in the yard over a considerable period, the intensity of illumination should be as high as for similar operations in interiors. Where the light is required only occasionally, a lower standard will suffice.

Light is the most important auxiliary of the armed guard. The amount of light to be used for the protection of buildings and materials depends upon the importance of the property, the likeli-

hood of attack or theft, and the number of guards; the more generously light is employed, the smaller the force required for patrolling the property. For $1000 per year as many as twenty 500-watt units can be operated all night every night. In other words, the cost of adequately illuminating a strip of land 200 feet wide and one-half mile long is no more than that of employing one additional night watchman. To be effective the lighting system must be comprehensive. The safe way is to allow no dark spaces or corners anywhere about the property. Complete protection demands lighting of the boundaries (see Fig. 102) so that no unauthorized person can enter the plant without being observed and at times of strikes it is frequently necessary to sweep any adjacent open fields and approaches with light. In protective lighting especially, it must be remembered that an object is seen in detail by the light which comes from it to the eye and not by the light that comes from the light source to the eye. The aim, therefore, is to throw the light upon the object to be seen and to have as little as possible of the light coming direct from the source to the eye. An object is often discovered, however, in silhouette, that is, by means of light coming to the observer, not from the object, but from a location beyond it. It is a recognized advantage in military practice for a sentry to arrange if possible to have any intruder between himself and the sky, when illumination is deficient, before the challenge is given. In artificial lighting, any moderately illuminated area such as the area beneath units or an illuminated fence or building takes the place of the sky as a background. Illumination as a means of protection, both at the boundaries of a plant and within the yards, was insistently urged by the Military Intelligence during the war. The greatly increased application of light in this manner serves to show that adequate lighting of the yards is frequently profitable from a general-utility standpoint alone. The electrical energy required with modern incandescent-lamp equipments for general illumination of yards is of the order of 0.02 to 0.1 of a watt per square foot.

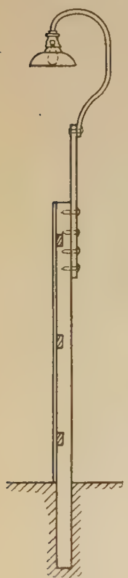


Fig. 102. Method of Mounting Units to Provide Zone of Light

Types of Equipment. Types of equipment which find application in exterior lighting about an industrial plant are the following:

Dome-type, enameled-steel reflectors
Radially fluted, enameled-steel reflectors
Prismatic-refractor fixtures
Angle-type, enameled-steel reflectors
Flood-lighting projectors

In selecting any of the equipments for outdoor service one should be careful to secure well-constructed, weatherproof fixtures.

Dome-Type Reflector. The dome-type reflector was discussed in Part II. These reflectors are suited for use on brackets or mast arms attached to buildings or poles distributed through the yard. The efficiency of the units is high; they deliver about 75 per cent of the light from the lamp below the horizontal. They give excellent protection from glare, as compared with other outdoor-lighting units, and their cost is low. Except in the case of units of 100-watts or less, which may be installed as low as 15 feet above the ground, the mounting height should not be less than 18 feet. Higher suspension will further improve conditions for vision. A degree of uniformity satisfactory for general yard or roadway illumination will be secured if the spacing between the dome units does not exceed four times their mounting height.

Radially Fluted Reflector. In the radially fluted dome reflector, whose efficiency is like the dome type, the major part of the reflecting surface is essentially horizontal and the dome section at the center allows the lamp to be drawn up so high that the rays from the filament strike the fluted surface at an angle so acute that a large percentage of the light is reflected specularly and directed at the higher angles. Because of this wide distribution the units may be mounted at spacings up to six times the height of the lamps above the ground. The lamp filament is of course not shielded from the eye with these reflectors and it is therefore particularly important that even the small sizes of lamps be mounted not less than 15 feet above the ground, and that the height of sizes above 100 watts be 20 feet or more. Radially fluted reflectors are available without the central dome part; their use in this form is not to be recommended, however, because the lamp filament must necessarily be placed at a considerably greater

distance below the fluted reflecting surface, and the light therefore less effectively redirected. The dome radially fluted units are in general also to be preferred to the flat-cone reflectors shown in Fig. 68.

Prismatic Reflector. The prismatic-refractor fixture, Fig. 106, gives the widest distribution of all the equipments for exterior use, and protects the eye from glare better than does the radial-wave unit. The angle at which the maximum candle-power is directed depends upon the position of the filament and hence of the fixture socket with reference to the refractor. For yards the fixtures should be ordered with the socket in a position such that the maximum candle-power will be delivered at least 15 degrees below the horizontal. The intensity near the horizontal is then greatly reduced and the glare is not excessive. Refractor units should be mounted 20 feet or more above the ground and spaced not more than 8 times their height.

Angle-Type Reflector. The angle type of enameled-steel reflector is used for spaces between buildings too wide to be lighted adequately from dome reflectors on brackets at the structures or for open spaces before buildings where it is necessary to avoid setting poles. Such units should in general be mounted 25 feet or more above the ground and the spacing between units on a building face should be within two to three times their mounting height. Angle reflectors deliver from 60 to 65 per cent of the light from the lamp below the horizontal.

The four types of equipments discussed above must be distributed at moderate spacings on supports relatively near the area to be illuminated. This distribution of units results in the marked advantage that at a given point, light is usually received from several lamps and from different angles, thus obviating dangerous shadows and minimizing the effect of the outage of an individual lamp. The equipments are efficient and their cost is relatively low. To mount the fixtures, however, it is sometimes necessary to erect additional poles or other supports and to extend the lighting circuits.

Flood-Type Projectors. With flood-lighting projectors, the light is confined within relatively narrow angles; the beams are of high candle-power, and the light may be projected to a given

area at a distance. Equipments may be mounted at a few favorable points, often on existing circuits. Thus the cost of additional poles and wiring may sometimes be saved, but this advantage is usually more than offset by the relatively high cost of the projectors themselves and the somewhat lower utilization of light flux. This is particularly likely to be the case if a sufficient number of lamps are installed at different points about an area to eliminate long, sharp shadows. Furthermore, it is difficult to arrange flood lamps so that objectional glare will not at times be experienced, nullifying much of the value of the light. Nevertheless, when they can be carefully located and mounted high on pole brackets, platforms, or roofs of buildings, excellent illumination may often be secured. Flood-lamps are particularly valuable for providing light quickly in an emergency, supplementing regular systems, and temporarily reinforcing the intensity at certain points. They fill a great need in illuminating locations where no wiring can be carried or no supports spaced for other types of fixtures.

For general application about an industrial plant, flood-lighting units of medium beam-spread, from 15 to 30 degrees, are most often suitable. The desirable beam-spread under given conditions obviously depends upon the area to be illuminated and the distance of the projector from this surface. Flood lighting from one direction only should if possible be avoided when there are any materials or obstructions to cast shadows, for these will of necessity be long, sharp, and dark. However, if flood-lighting lamps can be mounted on two or more sides of a space excellent illumination will frequently result. In general the units should be mounted on buildings, platforms, or bracket arms at least 30 feet above the ground. A mounting height of 40, 50, or even 60 feet is usually preferred. Flood lamps of high candle-power and narrow angle on building roofs or elevated platforms serve to light long approaches to a plant or to sweep open fields and water fronts.

STREET LIGHTING

Different from Interior Lighting. The design of a street-lighting system, at the present time, has little in common with interior-lighting practice. The intensities which here prevail are of a decidedly lower order of magnitude; variations of illumi-

nation on the street surface in the ratio of 100 to 1, are the general rule, and even the types of lamps used and the methods of supplying them with energy are radically different from those used in interior lighting. The explanation of this situation lies in the fact that in street lighting the areas to be covered are vast and the funds usually considered available for the purpose pitifully small. A single office space 50×100 feet will frequently be supplied with more lamps and a greater wattage than three or four miles of a principal thoroughfare in the same city.

For many years, then, the task of the street-lighting expert has been principally that of so distributing an insufficient amount of light as to produce the greatest practicable effect. An exception to this rule is found in the best business districts where high-intensity, or "white-way," lighting is properly considered as an expenditure for advertising to be met either by the city itself or by the local merchants. Ordinarily, however, this high-intensity system covers but a small fraction of the total street mileage of a city.

For ornamental systems, standards should usually be spaced from 65 to 100 feet apart, opposite each other on both sides of the street, and the light source should be at least 12 feet, preferably 15 feet or more, above the pavement. For this service single light standards, of which Figs. 43 and 107 are examples, are far more efficient than cluster lights as well as more pleasing in appearance. Either high candle-power magnetite arc, or Mazda-lamps may be used.

Requirements of Utilitarian Street Lighting. The following discussion of the requirements of utilitarian street lighting, that is, lighting of residence streets and thoroughfares, is abstracted from an article on this subject by Mr. J. R. Cravath.*

STREET LIGHTING FOR SMALL CITIES AND TOWNS

Before street lighting can be intelligently planned it is necessary to have a clear idea of just what is to be accomplished by the lighting. While the general objects can be stated in a few words, an analysis of these soon leads one into a rather complicated situation which can be only briefly reviewed in this article.

Stated in very general and popular terms, the objects of lighting streets can be summed up as follows:

1. In all classes of streets the least that can be expected of street lighting is to enable a person to see his way about at night.

Electrical World, Sept. 1, 1917.

2. On some classes of streets the production of an especially well-lighted effect, either on account of congested traffic or because of the ornamental and advertising features, is desired in addition to the first objects named.

On a large majority of streets lighting for purposes of seeing, without much regard to producing enough light for advertising or ornamental effect, is all that can be expected. Even on such streets, however, there will naturally be some difference in the severity of the requirements. The more traffic on a street the greater is the amount of outlay justified for street lighting and the greater is the necessity for safeguarding users of the street from collisions and attack.

As to the things it is especially necessary to see on a street at night in order to see one's way about, one might elaborate at length and in great detail, but to mention a few of the principal ones will suffice. For both pedestrians and drivers irregularities and obstructions of the street surface must be seen. Likewise, other persons using the street must be seen in order to avoid collision. The value of street lighting in preventing crime is probably about in proportion to the quantity of such lighting. On some of our worst-lighted streets it is of little value, while on the most brightly lighted downtown streets conditions as to crime prevention are virtually equivalent to daylight.

Technically the object of street lighting is to produce a certain amount of brightness on street surfaces and upon users of the street. In the daytime there is such a superabundance of light that the distribution of brightness on street surfaces and various objects need not be analyzed very closely; but where the amount of artificial light must be as meager as it is in a majority of streets in small cities a much closer analysis is needed.

DISTINCTION BETWEEN INCIDENT ILLUMINATION AND SURFACE BRIGHTNESS

The distinction between the illumination incident upon a surface (such as a pavement, sidewalk, tree, vehicle, or person) and the surface brightness of such objects must always be kept in mind. It is brightness that we see, that produces the effect on the eye. The illumination on a surface produces the brightness we see, but it does this only by virtue of the light reflected from the surface. That is, the brightness is always proportional to the incident illumination minus the loss by absorption. Since the reflecting power of various surfaces differs greatly, their brightness under a given illumination differs in like proportion.

Between a very new macadam or concrete surface and black mud there may easily be a difference of ten to one in diffuse reflecting power. To produce equal brightness, therefore, the illumination would have to be ten times greater on the black mud than on the light macadam, and the unfortunate thing about this is that there is usually less money available to illuminate the mud than to illuminate the macadam. By daylight a considerable portion of our seeing is by virtue of the different color and reflecting power of various surfaces, although differences in illumination, commonly known as light and shade effect, also have their influence. At night, with street lighting, differences in illumination from different directions causing light and shade have a much greater effect.

SILHOUETTE EFFECT

How important they are was probably not realized until 1910, when Preston S. Millar pointed out that a considerable portion of our seeing on the streets at

night is by virtue of the silhouette effect. That is, we see many upright objects, such as persons and automobiles, at a distance not so much by the light reflected from them as by the light background against which they appear as silhouettes. This is especially true in large cities where the background consists almost entirely of pavement, sidewalks, and buildings, which are better reflectors and consequently appear brighter than vehicles and persons in dark clothing. Fig. 103, taken from Mr. Millar's original paper before the Illuminating Engineering Society dealing with silhouette effect, shows the latter very clearly.

On dirt streets or where oiling has rendered the pavement a very dark color the effect is not so pronounced. However, even oiled streets, if so well traveled by automobiles as to take on a kind of glint or polish, reflect considerable light by what is known as specular reflection in distinction to diffuse reflection. Specular

Fig. 103. Cab Is Seen by Silhouette Effect While More Distant Features Are by Direct Illumination

reflection is the same as that which takes place from a mirror. It makes these oil-polished street surfaces appear quite bright at certain angles.

If the background is not brighter than the object, the only way the object can be seen is by having sufficient illumination upon it to make it enough brighter than its background to be recognized. Sometimes the same object is seen partly by silhouette and partly by illumination upon it, as in the case where part of the object is seen against a bright background and part against a dark background. The bearing of these silhouette and illumination effects on the spacing and equipment of street lamps is taken up later.

Road obstructions, such as stones and bricks, for example, may be seen either by illumination or silhouette, but are usually recognized fully as much by the shadows they cast as by any reflection from their own surfaces. Holes and depressions in sidewalks and pavements are usually also recognized by shadows, except when close under a street lamp.

EFFECT OF SHADOWS

The National Electric Light Association committee on street lighting for 1914 made some elaborate experiments on a street in New York City to determine the merits of various lamp spacings and mounting heights and various types of light distribution from the lamp. Considerable attention was given to tests in which a number of observers were required to locate obstructions or targets placed in the street as they walked or drove along. The principal result of this investigation showed that obstructions such as stones in the street could be better seen with lamps so spaced as to give some shadows behind these obstructions than with the lamps placed at such frequent intervals and so equipped as to produce a more uniform illumination with less pronounced shadows. In all of these experiments, however, the lamp spacing was relatively short as compared with common practice in smaller cities. As uniformity of illumination comes high in first cost on account of the large number of lamps and lamp supports required per mile of street, there is no great danger that streets will be lighted too uniformly for best results in the smaller cities.

Seeing by glint effect is a term used among engineers to apply to effects obtained when surfaces are wet or where they are highly polished so that there is

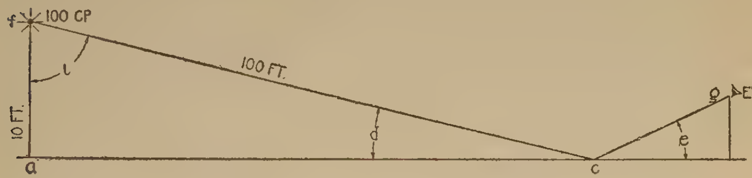


Fig. 104. Diagram for Brightness at Different Points

specular reflection from small portions of them. On rainy nights glint from the wet sidewalks and pavements takes the place of the partially diffuse reflection ordinarily received. Many images are then seen of the street lamp reflected from the wet pavement and pools of water. Glint is also especially useful in locating mudpuddles with the aid of rather distant street lamps.

In connection with seeing by silhouette, the value of this effect is in many cases greatly increased by the fact that there is just enough glint or specular reflection from the paving or sidewalk for the illumination at points midway between street lamps to produce much greater brightness in the direction of the eye than if the whole of the street were a purely diffuse reflecting surface.

Referring to the diagram of Fig. 104, f is a street lamp 10 feet (3 m.) above the ground and g is the eye of an observer. What is the brightness of the street surface at points a and c to the observer? We will assume first that the street surface is a new, white, dusty macadam which will approach a diffuse reflector in its characteristics. Now a diffuse reflector will appear equally bright from all directions, no matter from what direction illuminated. Consequently the brightness at various points along the street will always be directly proportional to the illumination. Thus, at point a if the lamp is of 100 c-p., the illumination will be 100 c-p. divided by 100 (which is the square of the distance), or 1 foot-candle (10.08 lumens per sq. m.). At point c, assuming that the lamp emits 100 c-p. in

that direction also, and that the distance f to c is 100 feet (30.48 m.), the illumination on the street surface at c will be by the same process of figuring 0.01 foot-candle (0.108 lumen per sq. m.) multiplied by the cosine of the angle i, or in other words by the ratio of 10 feet (3 m.) height to 100 feet (30.48 m.) distance, thus making the actual horizontal illumination at c 0.01 foot-candle multiplied by 0.1 or 0.001 foot-candle (0.0108 lumen per sq. m.). The illuminations and brightness would therefore be in the ratio of 1 at the point a to 0.001 at the point c. Evidently with an object between the eye and point c as a background there could be very little silhouette effect, while between the eye and point a there would be considerable.

If, however, the street surface is glossed with oil or moisture, the character of reflection from it is entirely changed. Instead of appearing equally bright in all directions about any given illuminated spot, it will appear very much brighter when viewed from an angle equal to the angle of incident light. Consider the light which falls on point c from the lamp at f and is reflected to the eye at g. If angles d and e are equal, and if point c were a mirror, the brightness entering the eye from point c would be practically the brightness of the source of light at f. If the point c is a piece of glossy oiled street surface, it will not behave exactly like a mirror, nor will it act as a diffuse reflector, but its action will be intermediate between the two. It will appear very much brighter when viewed from a direction approximating cg than from other angles. The point a, on the other hand, will appear considerably less bright than if it were a diffuse reflector. This tends to counteract the enormous difference in illumination falling upon these two points. The practical effect of this as brought out by Millar in various tests is that even on an asphalt street which does not have the polish common to heavy automobile traffic the brightness varied only at the ratio of 2.7 to 1 with lamps 260 feet (79.25 m.) apart, while the horizontal illumination varied forty to one. Here again it may be noted that the polishing of a street pavement due to heavy traffic of any kind is more conducive to uniformity of brightness in spite of the non-uniformity of illumination than are the conditions prevailing in the smaller cities. However, these points must be recognized in all classes of street-lighting problems. It should be remembered in considering the illumination and values cited in Fig. 104 that no allowance is made for any illumination that may be obtained on point c from another lamp placed at the back of the observer.

RELATIVE VALUES OF HORIZONTAL AND VERTICAL ILLUMINATION

There has always been considerable discussion in street-lighting circles as to the relative value of vertical as against horizontal illumination for street-lighting purposes. It is now generally recognized that both the horizontal illumination on the street surface and the vertical illumination on vertical objects such as pedestrians and vehicles must be taken into account. The relative weight given to these two in making up a good street-lighting system will depend very much on the character of the street surface. The importance of the silhouette effect has already been enlarged upon. It is evident that in producing silhouette effect, illumination of the street surface is the important thing. However, if the street surface is so dark that it is difficult to get a well-illuminated background, one must fall back upon vertical illumination of objects. It is largely a waste of time to discuss the relative importance of vertical and horizontal illumination,

because with any practicable mounting heights of lamps the illumination midway between lamps giving vertical illumination will be approximately a constant ratio to the horizontal illumination, and no amount of practicable shifting of lamp height and spacing is likely to change this constant enough to have much practical bearing on the subject under discussion at this time.

LAMP SPACING

We have seen that variations in intensity of illumination falling on the street surface from points immediately under lamps to points midway between are necessarily very large even with the most skillful use of appliances for directing the light of the lamp in directions where it is most needed. The figures given in connection with Fig. 104, already explained, where there is shown a variation of a thousand to one within 100 feet (30.48 m.) for the horizontal illumination, illustrate this forcibly. However, with more frequent spacing and by figuring in the effect of neighboring lamps these differences are rapidly reduced. For brightly lighted city streets a variation of ten to one between lamps at points on the street surface is not likely to be noted. Where lamps are as frequently spaced as on business streets the question of improving the uniformity of illumination does not offer itself. This applies to the present-day common spacing of ornamental systems, which are from 60 feet to 150 feet (18.29 m. to 45.72 m.). With special care this distance can be exceeded and still produce satisfactory uniformity, although the ornamental effect may not be what is desired. In outlying streets where first cost tempts the designer to space lamps at long intervals the poorly illuminated spaces midway between lamps come in for first consideration. On such streets chief interest centers on the points of minimum illumination between lamps. Anything and everything which will bring up this minimum between lamps is desirable if it can be obtained for a reasonable outlay. With a given lamp equipment the illumination midway between lamps will fall off approximately inversely to the square of the distance. That is, doubling the distance between lamps reduces the minimum illumination to one-fourth. Add to this the fact that the longer the interval between lamps the less is the amount of brightly lighted background against which things can be seen by silhouette effect and difficulties are further increased. Lamp spacings of 600 feet to 1000 feet (182.88 m. to 304.8 m.), which in years past have been so common among smaller cities, are entirely inadequate and inefficient. Furthermore, under modern conditions they are unnecessary from the economy standpoint.

AVOIDANCE OF GLARE

The avoidance of glare has long been recognized among experts as desirable in street-lighting practice, because it has been known that the existence of glare from lamps near the line of vision causes a decrease in the seeing ability of the eye —or, in other words, in the visibility of objects—so that to all practical intents and purposes more light is required on objects in order to see them clearly than if the source of glare were removed. Quantitative investigation of this subject has been made at considerable length by A. J. Sweet, some of whose results have been checked by Preston S. Millar. All of these results show that there is considerable disturbance of vision when a bright lamp is brought within 15 angular degrees of the center line of vision. As the effect of glare increases rapidly as the lamp is brought nearer to the center line of vision, especially within 6 to 8 degrees, there

is considerable to be gained in efficiency of illumination as measured from the ocular standpoint by hanging the lamp as high, and consequently as far out of the ordinary line of vision, as possible. While no very exact figures can be given, it may be said in a general way that unnecessarily low hanging of lamps may often be the equivalent of throwing away half of the light generated because of the depressing effect on vision of objects which must be seen past a bright street lamp. The use or non-use of a diffusing globe in a lamp apparently has very little effect on the glare, the glare effect being dependent upon the candle-power; or, to be more exact, it depends, according to the best information obtainable, upon the square root of the candle-power of the lamp used as emitted in the direction of the eye. The only feasible remedy for street-lighting glare yet evolved is the increase in mounting height of the lamps, and this is well worth while, especially in the range from 10 feet to 15 feet (3 m. to 4.5 m.). According to Sweet's investigation, if the glare effect be taken as 1 at a height of 32 feet (9.7 m.), it becomes about 1.9 at a height of 22 feet (6.7 m.), about 3 at a height of 16 feet (4.8 m.), 4.3 at 15 feet (4.5 m.), and 8.4 at 12 feet (3.6 m.).

Interference with street lighting by shade trees is a very live subject in the majority of cities, and especially in the smaller cities and towns under consideration. While the majority of such towns have many shade trees, there is considerable difference in the proper method of treatment. In some streets the trees are very large and permit of trimming high to prevent interference with lighting. In other places the trees are of an age where trimming high enough to prevent interference with the lighting is out of the question. Where the trees are too small to admit of high trimming, center-lamp suspension will usually be necessary to prevent undue shadows. In such a street no locations can be found except in the center which will not involve considerable obstruction of the light by shade trees. On the other hand, where the trees are very large so that they can be trimmed high to form a high arch over the street the principal trouble with shadows is not from the boughs and leaves but from the large trunks, which standing in line along the parkway form an effective light barrier for the sidewalk. On such streets the location of lamps in line with one of the row of tree trunks permits the complete lighting of the roadway and of the sidewalk on the side on which the lamp is located, and causes light to shine through the row of trunks on the opposite side of the street at an angle sufficiently oblique to permit the location of the sidewalk always to be seen, and the area of the sidewalk in the shadow is reduced to a minimum.

Importance of the Various Factors. To sum up Mr. Cravath's findings, we must have direct illumination on the surface of the street and the sidewalk, which, with the resulting shadows, will render irregularities visible. Direct light is also necessary in order to recognize the features of a passer-by; that is, to identify him as a friend or an enemy. Heavy shadows on the other hand, as very thick foliage and tree trunks, tend to reduce the efficiency of the illumination, particularly with respect to safety from attack.

Silhouette effect is the greatest aid in discerning large objects on the road or on the sidewalk. Glint assists in increasing the

TABLE XXV

Important Factors in Street Illumination

(*A* indicates greatest importance)

Large Units	Small Units	Factor	Pedestrian	Slow-Moving Vehicles	Rapidly Moving Vehicles
	Best	Direct Ill.	A	A	C
Best	....	Silhouette	C	B	A
Best	....	Revealing shadow	B	C	B
Good	Good	Glint	D	D	B
Depends on height	Depends on height	Glare	C	A	A
Usually bad	....	Obscuring shadow	B	D	D

apparent brilliancy of a specularly reflecting roadway and also reveals puddles on the sidewalk. On the other hand, glare from brilliant lamps tends to reduce one's ability to see; or, in other words, the effectiveness of the illumination.

Analysis of Light Sources. At present the only two electrical illuminants to be considered for street lighting are the gas-filled tungsten lamp and the luminous- or magnetite-arc lamp. The enclosed carbon-arc lamp is now virtually a matter of history, and the flame carbon arc likewise. Magnetite lamps are available in sizes ranging from 300 to 500 watts, approximately 3000 to 9000 lumens (see Table IX), and series incandescent lamps in all sizes from 600 to 10,000 lumens (see Table III). The question of small units closely spaced versus large units at greater intervals, is one on which there has been almost endless discussion.

Table XXV shows the relative importance of the several factors from the standpoint of the pedestrian, the slow-moving vehicle, and the rapidly moving vehicle. The same table also shows the comparative rating of systems of large and of small lamps with respect to each of these criteria.

It will be seen that, from the standpoint of the pedestrian and the slow-moving vehicle, those qualities possessed in greatest degree by an installation of small units closely spaced are in most demand, while the requirements of the autoist are more nearly met by the use of powerful light sources at necessarily greater

intervals. Residence streets are usually frequented more by pedestrians and the foliage is likely to be dense on these streets. They should therefore be equipped with lamps of small or medium candle-power (250 c-p. or less at a spacing of not more than 250 feet and at a height of from 15 to 18 feet above the street). On the other hand, for principal thoroughfares an average spacing distance of from 250 to 300 feet should be chosen and the largest size of lamp used, up to perhaps 1000 candle-power, that the appropriation will cover.

Equipment. The most effective type of reflecting equipment for either arc or incandescent lamps in street lighting, especially as regards that large portion of the city outside of the "white-way" district, where questions of economy and efficiency are paramount, has been the subject of much controversy. There are today four types of reflecting equipment in use for street lighting, and similar results as regards light distribution are obtained from these equipments, whether the arc or an incandescent lamp is used as the light source. These four types are:

1. The flat reflector without diffusing globe (Fig. 68).
2. The same with diffusing globe (Fig. 106, at *B*).
3. The prismatic refractor enclosing or partially enclosing the light source (Fig. 106, at *A*).
4. The prismatic refractor within a globe of stippled or pebbled glass, which produces a slight breaking-up of parallel rays of light without greatly altering their direction (Fig. 105).

The general trend of development in arc lamps has been toward increasing the relative proportion of light flux emitted in zones near the horizontal, and this trend was markedly advanced upon the introduction of the magnetite lamp in which the arc was held in a fixed position just below a widely distributing reflector. The general argument of those favoring the use of prismatic refractors has been that such accessories make it possible to direct even a greater proportion of the light where it is most needed; by means of a refractor one can more than double the normal candle-power of the lamp and thus increase the intensity midway between units, at which point the illumination is usually not more than 5 to 10 per cent of the average over the street surface. At the same time the intrinsic brilliancy of the refractor is considerably less than that of an exposed arc, or lamp filament.

On the other hand, the more conservative who favor the use of the old opal-globe fixtures contend that with the refractor distribution, much of the light fails to reach the road surface and is therefore wasted; that the glare from such units seriously interferes with vision; that street intersections are inadequately lighted; and, furthermore, that with refractors there is not sufficient light on that portion of the street surface in the immediate vicinity of the lamp to insure that vehicles or pedestrians on other parts of the roadway may be rendered visible in silhouette against this brighter area. The opal globe is not open to these objections in the same degree. It is, however, deficient in revealing smaller obstacles or irregularities in the road surface throughout an extended region midway between lamps. In these darker stretches the pedestrian as well as the driver of a vehicle proceeds with difficulty and with a feeling of insecurity.

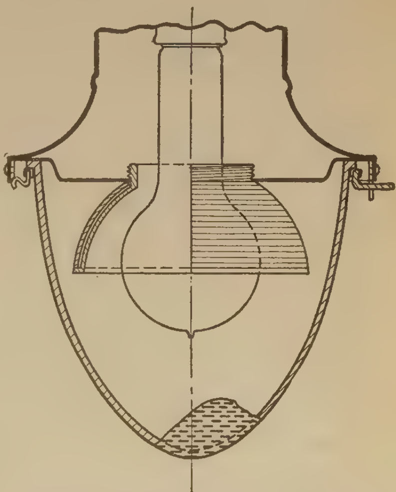


Fig. 105. Prismatic Refractor within Globe of Stippled or Pebbled Glass, which Breaks up Parallel Rays

A disadvantage of every form of street-lighting unit is that in the absence of most rigid inspection and maintenance the efficiency of the system becomes rapidly impaired due to the collection of dust and grime.

The combination of dome refractor and stippled globe illustrated in Fig. 105 has been developed in an effort to combine in one fixture the advantages of both the opal-globe and refractor units and to minimize the depreciation in candle-power due to dirt. Distribution curves of these three types of units equipped with a 1000-candle-power (10,000 lumens) Mazda C lamp are shown in Fig. 106. It will be noted that at all except the high angles the candle-power of the stippled-globe unit is considerably greater than for the original type of refractor. While the light is not entirely cut off at angles from 85 to 90 degrees, the average candle-power is here less than one-half that of the standard

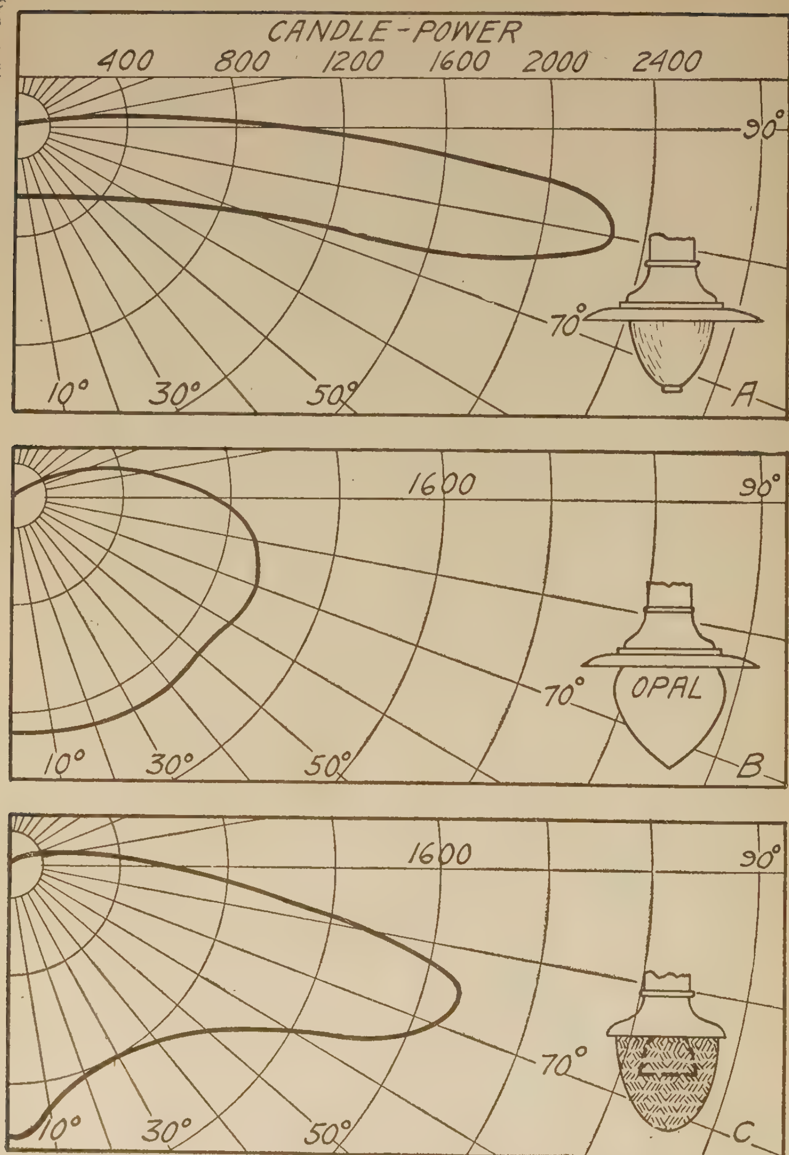


Fig. 106. Candle-Power Distribution of Lamps for Street Lighting

refractor, and but two-thirds of the intensity of the opal-globe unit. On the other hand, the summation of lumens from 0 to 60 degrees is actually greater for the stippled-globe fixture than for the opal globe, and consequently a higher intensity at the intersection and a brighter area beneath the unit for silhouetting are provided. An additional feature of this type of fixture is the fact that it can be made practically air-tight.

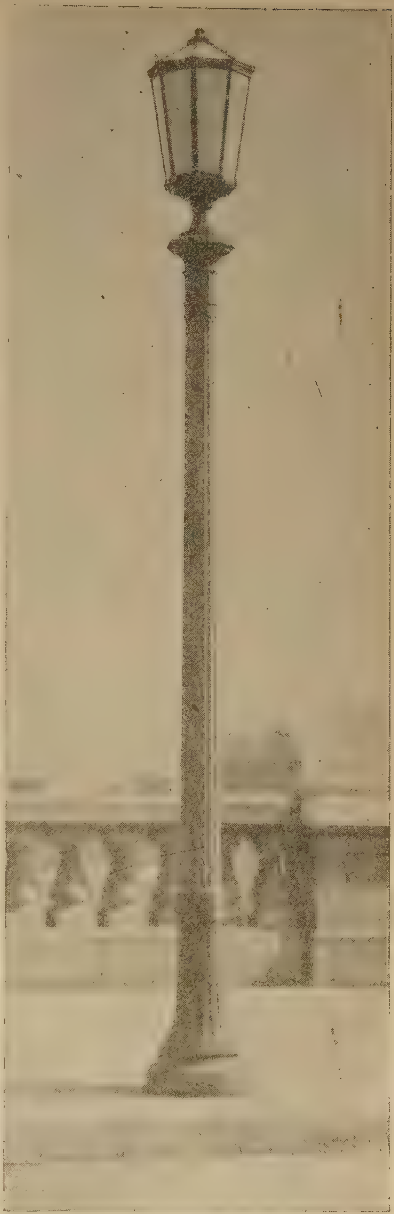


Fig. 107. Single-Light Standard for Street Lighting

Street-Lighting Systems. In the past, street lamps have usually been operated from series circuits, the principal reasons being:

First, the arc lamp is inherently a constant-current device and gives its best operation and greatest efficiency on series rather than on multiple circuits.

Second, the series circuit is the simplest and most efficient method of supplying energy to comparatively small units scattered over wide areas; in many cases electric street lighting antedated the general use of electricity in residences by a considerable period.

Third, a separate system of distribution has furnished the only satisfactory means of automatically lighting and extinguishing street lamps from the central station.

At the present time, when multiple incandescent lamps are available at a very high efficiency, and when a multiple system of distribution is found in almost every locality, there is but one

valid reason for the duplication of a distribution system, and that is the convenience of turning lamps on and off. If some form of remote control switch for individual lamps were available and could be utilized simply and inexpensively, the legitimate field of the series circuit would be closely limited. Meanwhile, every effort is being put forth to simplify and reduce the amount of apparatus required for such circuits. Several attempts with varying success have been made to eliminate the moving-coil type of transformer or regulator, but as yet no such system has received the full approval of the manufacturers of the lamps with which they must be used. A preferable plan is that of constructing the moving-coil transformer in such a manner that it can be mounted out-doors on a pole at any convenient location, connected to the 2200-volt power mains and operated by a time or remote control switch. Often it is convenient to utilize such transformers for the extension of street-lighting service and to connect directly in series with the lamps of the nearest street-lighting circuit the remote control switches which operate them. Such a plan is especially advantageous in extended systems, as it often avoids the use of several miles of wire, which would otherwise be required between the nearest lamp of the new circuit and the sub-station.

PHOTOMETERS

Lummer-Brodhun Photometer. In addition to the Bunsen screen described in Chapter I, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 108, the screen S is an opaque screen which reflects the light falling upon it from L, to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces are ground to fit perfectly at *sr* and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from L which falls on *ar* and *bs* is reflected to the eyepiece or telescope T, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the

screen L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface sr pass through to the telescope T, while the rays falling on ar and bs are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disc of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disk and ring appear alike and the dividing circle disappears.

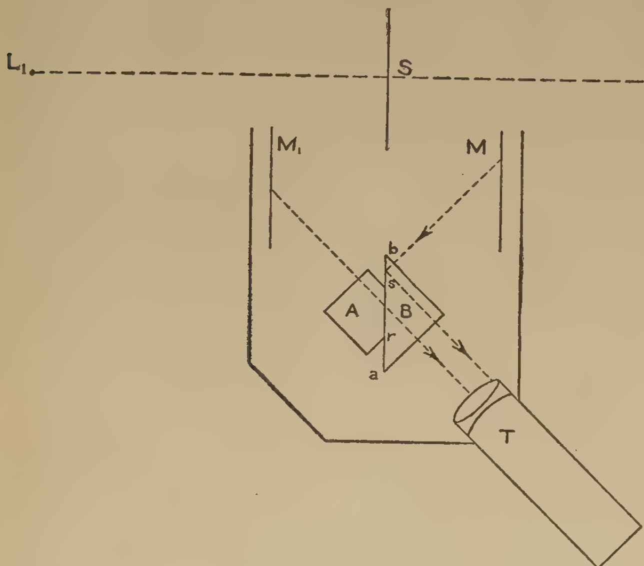


Fig. 108. Diagram of Lummer-Brodhun Screen

In using this screen it is mounted the same as the Bunsen screen, and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

A complete photometer with a Lummer-Brodhun screen is shown in Fig. 109, and a Bunsen screen and sight box are shown in Fig. 110. In Fig. 109, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen. If the lights

are properly screened, photometric measurements may be made in rooms having light-colored walls.

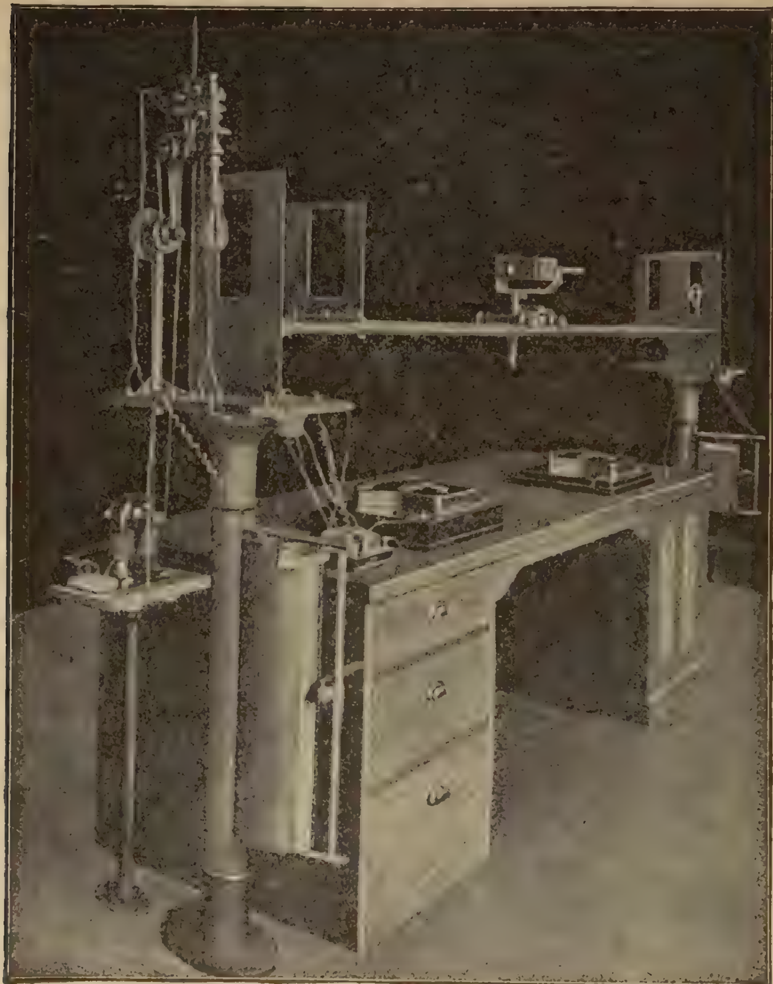


Fig. 109. Complete Photometer with Lummer-Brodhun Screen

Weber Photometer. As an example of a good portable type, the Weber photometer is shown in Fig. 111. This photometer is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

This apparatus consists of a tube *A*, Fig. 112, which is mounted horizontally and contains a circular opal glass plate *f*, which is movable by means of a rack and pinion. To this screen

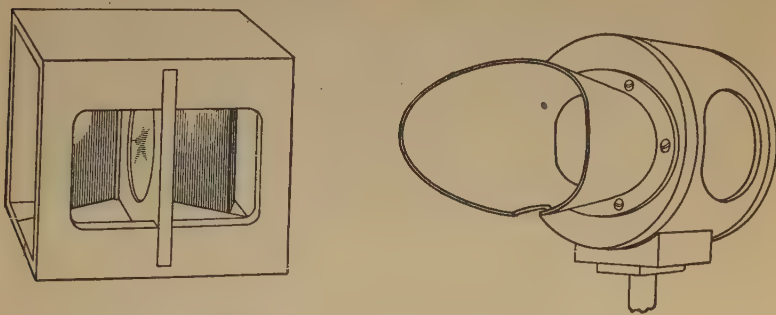


Fig. 110. Bunsen Screen and Sight Box

is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, either incandescent or oil, is mounted at the end of this tube. At right angles to the tube *A*

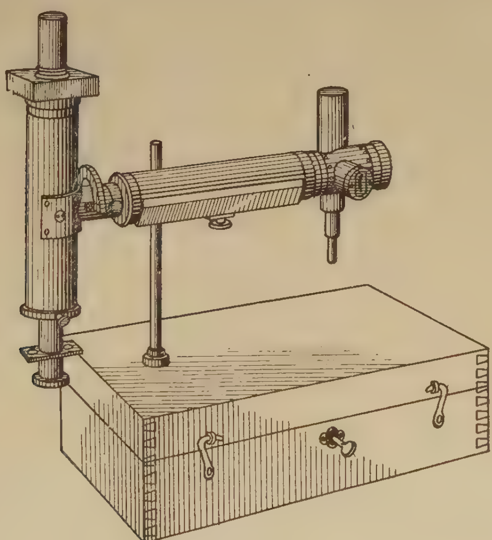


Fig. 111. Weber Portable Photometer

is mounted the tube *B* which contains an eyepiece at *O*, a Lummer-Brodhun contrast prism at *p*, and a support for opal or colored glass plates at *g*.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at g being noted. The light from this source is diffused by the screen at g, while that from the standard is diffused by the screen f. By moving the screen f, the light falling on either side of the prism p can be equalized. The value of the unknown source can be determined from the reading of the screen f, the photometer having previously been calibrated by means of a standard lamp in

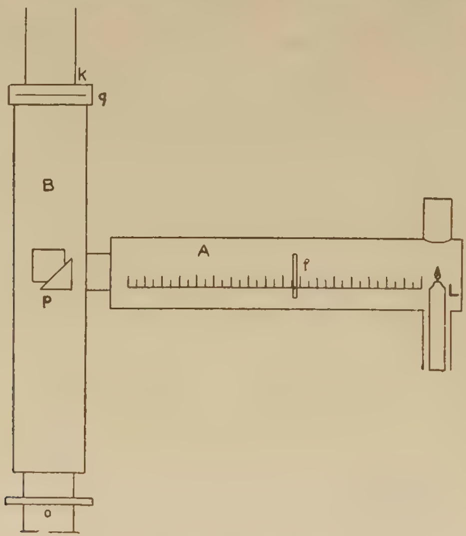


Fig. 112. Diagram of Weber Photometer

place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant C, when we have the formula

$$I' = C\frac{L^2}{l^2}$$

C corresponds to a particular plate at g; l is distance of screen f from the benzine lamp; and L is distance from the screen g to the light source being measured. Screens of different densities may be used at g depending on the strength of the light source.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at g, and turned so that it is illuminated by

the source being considered. Readings of the screen f are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

Portable Photometers. There is a large variety of portable photometers available which give more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of other instruments on the market is the "Universal" photometer, more commonly known as the "Sharp-Millar" photometer from the names of its inventors. Views of this instrument are shown in Figs. 113 and 114. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at B, and consists of a special form of Lummer-Brodhun optical screen. A standardized incandescent lamp C is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens G. The instrument scale is calibrated in foot-candles and in candle-powers.

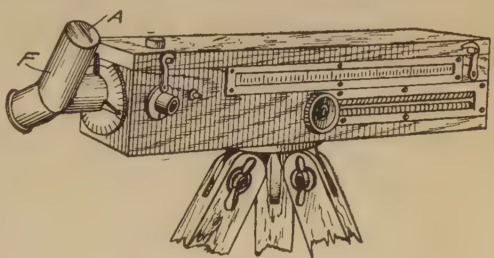


Fig. 113. Sharp-Millar Photometer

When illumination is to be measured, a specially selected translucent screen is placed at A and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at H. A second plate K is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of A and K the same. When the intensity of a light source is to be determined, the screen at A is replaced by a small aperture and a diffusing surface I is put in place of the mirror H. The illumination of I is now compared with the illumination of K, and when the two are

made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed, and, as ordinarily equipped, the range in foot-candles is approximately from .004 to 2000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, $24'' \times 4\frac{1}{2}'' \times 5''$, and its weight, fully equipped, of 8 pounds.

Macbeth Illuminometer. This consists of three main parts and various accessories, all contained in a convenient leather

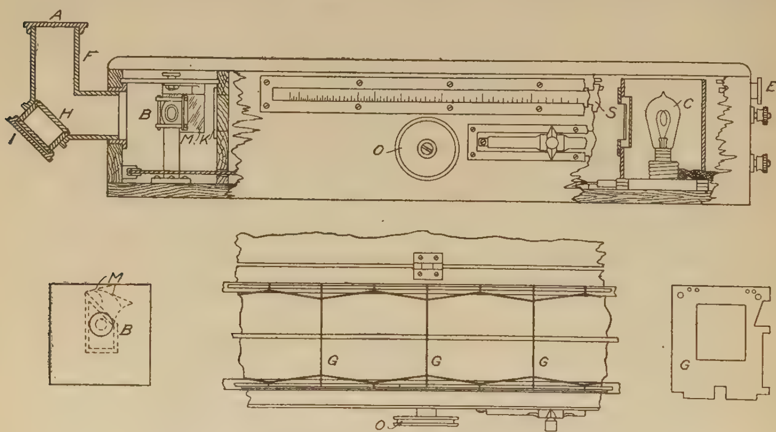


Fig. 114. Sectional View of Sharp-Millar Photometer

carrying case measuring $10'' \times 17'' \times 6\frac{3}{4}''$ and weighing, complete, 14 pounds, with all parts in place excepting the battery. The battery may weigh from $1\frac{1}{2}$ to 4 pounds, depending upon the kind and size of cells used.

The three main parts are the illuminometer, the controller, and the reference standard.

The illuminometer is shown in Fig. 115. A Lummer-Brodhun cube is mounted in the rectangular head. By removing the head from the tube and then taking out two screws the cube may be removed for cleaning. It is quite easily replaced, it being impossible to return it to a wrong position. The photometric field is viewed through the telescope. The aperture opposite the telescope is aimed or pointed toward the test plate, or any surface the

brightness of which is to be measured. In the tube, which is 9 inches long by $1\frac{3}{4}$ inches in diameter, is a diaphragmed carriage within which is mounted an electric incandescent lamp, the working standard. The lamp carriage is moved up and down in the tube by means of a substantial rack and pinion operating upon a square brass rod to which the carriage is fastened. This rod is seen projecting from the bottom of the tube, Fig. 115. On one side of the rod to which the lamp carriage is attached is engraved the direct reading scale calibrated from 1 to 25 foot-candles. The illuminometer weighs 20 ounces.

The second unit of the equipment, the controller, is supplied with a shoulder strap for convenience of operation and observation when in use. The controller comprises the battery for operating

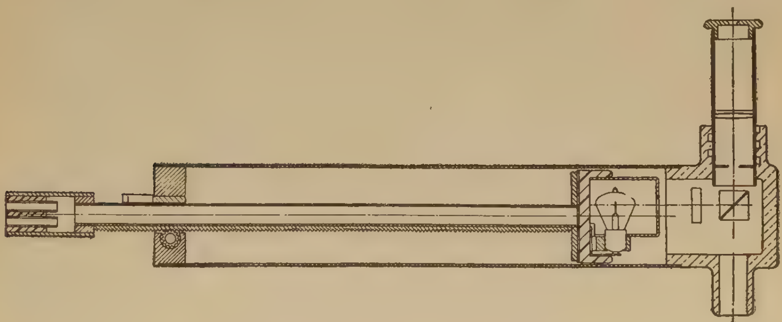


Fig. 115. Cross-Section of Illuminometer

the lamps, a Weston mil-ammeter, two close-regulating rheostats, one for the working standard and one for the reference standard lamp, hereafter called the reference standard, and a double-throw switch, by means of which the mil-ammeter may be brought into either the working-standard circuit or the reference-standard circuit.

In the third element, or reference standard, is presented an innovation in illuminometer design. A cross-section is shown in Fig. 116. By the use of the reference standard the illuminometer may be checked up at any time or place, without a dark room and an auxiliary photometric apparatus, and also without the inconvenience and expense of laboratory-standardized working-standard lamps. The ease of frequent calibration permits the use

of working-standard lamps at a very much higher efficiency than before, thus securing better color of light and considerably reducing the current demand and consequent battery capacity.

The elimination of the personal factor which is always present with illuminometers standardized by others is of considerable importance. In the Macbeth Illuminometer each operator standardizes the illuminometer against a known illumination intensity and thus compensates for the personal difference of various photometric observers.

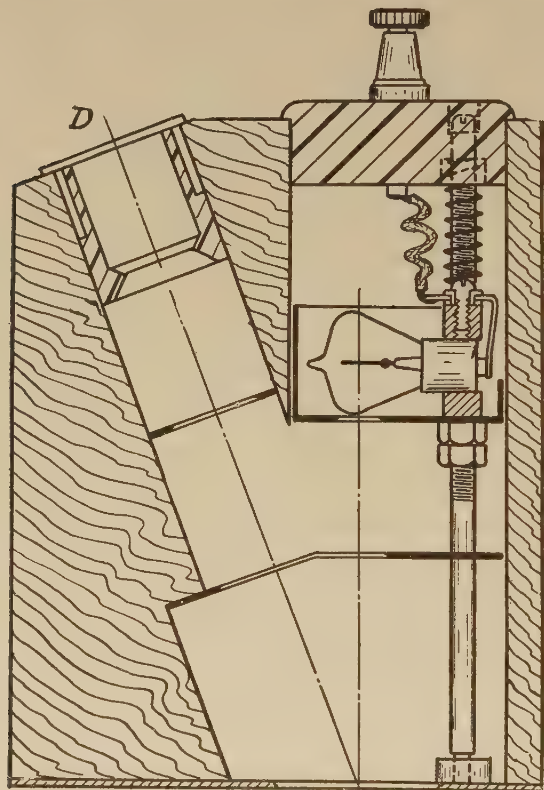


Fig. 116. Cross-Section of Reference Standard

The reference standard consists of a hardwood housing in which is mounted a standardized lamp, fully protected with diaphragm screens. The interior parts, after standardization, can be effectively sealed. The lamp used is seasoned and is run at

such low efficiency and for such short times as to insure the greatest possible constancy.

In use the standard is placed upon the test plate so that the plate is illuminated by the standardized lamp through the opening below the lamp. Before it leaves the factory the lamp is so seasoned and calibrated that when a current of the value given in the accompanying certificate is passed through the lamp there will be a definite intensity of illumination upon the test plate. The illuminometer may then be calibrated by placing the sighting aperture in the hole marked D and adjusting the current through the working standard.

Flicker Photometer. The flicker photometer is used for the comparison of different-colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen and, vice versa, any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side, will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material

having a diffusing surface and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eyepiece of the instrument and,

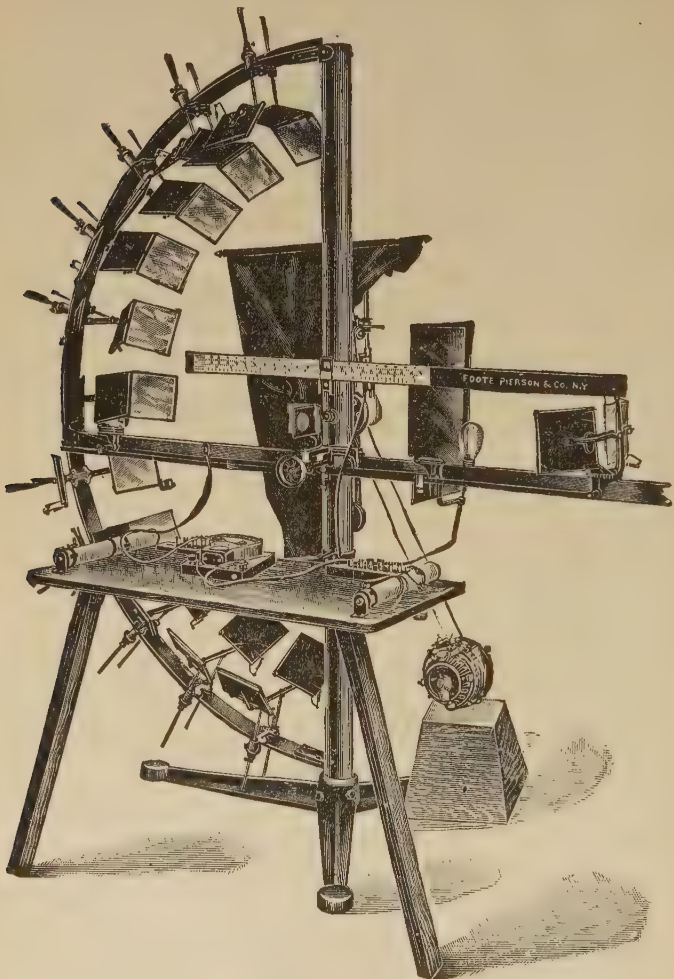


Fig. 117. Matthews Integrating Photometer

during the other part of the revolution, a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers, it is found that results with different-colored lights can be obtained which are comparable with results obtained with lights of the same color.

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be

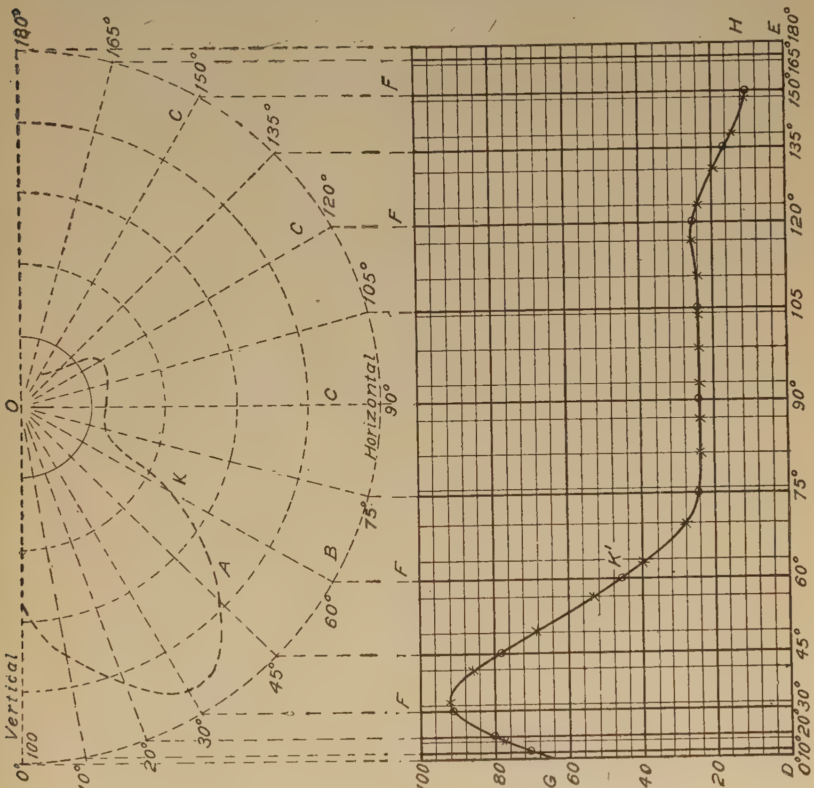


Fig. 118. Rosseau Diagram for Lamp with Bowl Reflector

obtained from Fig. 117. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Rousseau Diagram. The Rousseau diagram may be used for determining the mean spherical candle-power of a lamp when its

vertical-distribution curve is known. Fig. 118 shows such a diagram made up for a lamp with a bowl reflector. Where the horizontal-distribution curve of the lamp is not uniform, the values for the vertical-distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale *A* and a circle *B* is drawn with the source of light *O* as a center. Radii *C* are drawn at equal angles about the light source and extended until they intersect the circle *B*. The points of intersection of these lines with the circle are projected upon the straight line *DE*. Distances from this line are laid off on the verticals *F* equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line *DE* and a curve drawn through the points just determined, *GH*, divided by the base line, is equal to the mean spherical candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divided by the corresponding base.

ELECTRICALLY LIGHTED DINING CAR

ELECTRIC LIGHTING OF TRAINS*

GENERAL PRINCIPLES

Introduction. This text gives to the reader a general working idea of the train-lighting problem and a knowledge of the systems employed in this country. It is intended to give train-lighting electricians a general idea of the troubles encountered with such equipments and the cause of these difficulties. It presupposes a working knowledge of electric generators, electrical circuits, and storage batteries.

Early Applications. The problem of railway train lighting is not a new one. One of the earliest applications of the incandescent lamp and the storage battery was to train lighting, but the lamps were inefficient and the equipment was bulky and costly. As early as 1881 Camille A. Faure, the inventor of the pasted storage-battery plate, was granted a patent by the French Government on a combination including a generator driven by a belt from a car axle, regulating means for the generator, a storage battery charged by the generator, and incandescent lamps furnished with current from the generator or the battery or both. The same system was granted United States letters patent on March 20, 1888. The introduction of the tungsten lamp increased the efficiency of the system and reduced its cost and size to such an extent that in the last ten years train lighting by electricity has become the standard method.

The advantages resulting from the application of electricity to railway-coach illumination are obvious. However, as they are also important, they are enumerated as follows:

1. The horrors attending any railway wreck are in themselves bad enough, but when oil or gas lamps are in use, the

* The author wishes to thank the different companies whose equipments are described in the following pages for the use of illustrations furnished by them: also Mr. D. N. Balderston, of the axle lighting department of the Electro Dynamic Company and Mr. George E. Hulse, of the Safety Car Heat and Light Company for detail information. The author wishes to express his appreciation to Mr. V. J. Kelly and Mr. W. V. Benson, chief electricians, U. S. N., for their assistance in checking the manuscript and in preparing the illustrations.

additional terror of a fire and even of an explosion exists. In the case of a wreck neither fire nor explosion can result from the use of electricity as the illuminant.

2. When gas is used as a source of illumination, an unpleasant odor results if the gas is blown out and not promptly relighted.

3. The air in any crowded coach is at the best none too pleasant. Oil and gas lamps further vitiate the atmosphere; electric lamps do not.

4. The degree of illumination obtained from a few groups of oil or gas burners is not uniform and is very unsatisfactory at points midway between the sources of light. The oil and gas burners are so large that they cannot be well distributed on side walls, nor can they be used at all for berth lights. Electric light can be uniformly distributed and may be located in any convenient position.

5. The labor entailed in filling oil lamps and replacing the wicks and in cleaning dirty globes on both oil and gas lamps is considerable. This is entirely eliminated if electric illumination is employed.

6. Esthetic considerations are not to be overlooked. The more sightly arrangement of electric-light globes and their fixtures has largely helped in improving the interior appearance of coaches.

7. The application of electric lighting in railway coaches has been accompanied by the introduction of the companion of the incandescent lamp, the electric fan, which adds considerably to the comfort of the traveler.

Regulation of Generator. The problem of train lighting is principally one of generator control and regulation, with auxiliary devices to prevent the generator from being connected to the battery when its voltage is such that the battery will discharge into the generator; and of means to maintain constant lamp brilliancy independent of train speed or state of battery charge.

The regulation of the generator characteristic is in almost all cases accomplished by varying the field current, or strength of field, substantially in inverse ratio to the speed; in general, this is termed field regulation. There is another method of generator control, and this is by variation in belt tension, in which case the generator operates at a constant output.

The field control methods of generator regulation are of five general types:

Constant-potential regulation
Constant-current regulation
Modified constant-current regulation
Current regulation followed by voltage regulation
Current regulation followed by voltage regulation through ampere-hour meter control

The theoretical circuit for a typical axle light equipment in which the generator, the battery, and the lamps are connected directly across the two lines is shown in Fig. 1. When the gen-

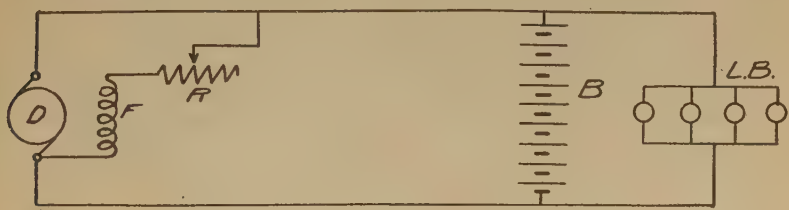


Fig. 1. Battery and Lamps in Parallel

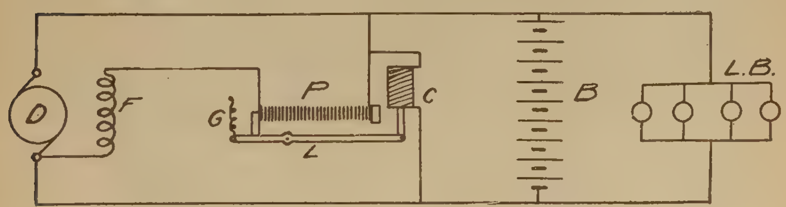


Fig. 2. Generator Provided with Constant-Potential Regulator

erator is to maintain constant voltage or constant current as the train speed varies or the state of battery charge changes, it is necessary to introduce in the field circuit, as at R, a variable resistance, which may have its value altered to maintain the desired voltage or current independent of the speed or other change.

Constant-Potential Regulation. If the regulation of the generator is to be toward constant voltage, then the apparatus which controls the variable resistance R must be connected so that it responds to changes in the voltage of the system. This regulating device in its simplest form comprises a solenoid with its winding connected across the line as though it were a voltmeter. The core of the solenoid C, Fig. 2, carries a lever arm L, which is

pivoted at its center; acting in the opposite direction to the solenoid is a spring *G;* the lever arm has a stud which bears upon a carbon pile *P* which is in series with the field circuit. If the voltage of the system tends to rise, owing to increased speed of the train, then the upward pull of the solenoid overcomes that of the spring *G*, and the stud moves away from the carbon pile so as to decrease the pressure on it. Decrease in pressure increases the resistance of the carbon pile, and the current through the shunt field of the generator is decreased in value. This is followed by a decrease in the generator voltage, which tends to bring about a balance between the pulls of the solenoid and the spring, this balance existing when the generator voltage is again at its proper value. If the generator voltage falls, owing to a decrease in generator speed, then the spring tension exceeds the pull of the solenoid, and the carbon pile is compressed. This reduces the

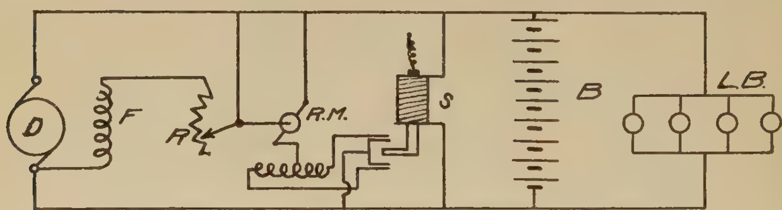


Fig. 3. Constant-Potential System with Regulator Motor

resistance of the shunt-field circuit, and the current through it rises, thus increasing the voltage. This sequence will continue until a balance again obtains between spring tension and solenoid pull.

Instead of using the simple form of solenoid varying the pressure on a carbon pile, the solenoid may be provided with a rocking segment which bears on different points of a grid resistance and thus varies the field current; or the solenoid may, as in some of the earlier forms, operate contacts which change the polarity of the fields of a small regulating motor which moves a contact arm over a circular arrangement of resistance units. This combination is shown in Fig. 3.

Constant-Current Regulation. If the generator equipment is designed to charge the battery at a constant current, the solenoid coil is placed in the battery circuit just as though it were an ammeter. The tension of the spring and the pull of the solenoid

are so adjusted that, with the predetermined current, a balance obtains. This arrangement is illustrated in Fig. 4. If the speed of the train increases and the current of the battery thereby tends to rise, the pull of the solenoid exceeds that of the spring, and the pressure on the carbon pile is reduced. This increases the resistance of the generator field circuit and reduces the generator voltage and current, which diminish until a balance obtains between the solenoid pull and the spring tension. This condition exists when the predetermined current is flowing. Constant-current systems have a voltage which varies with the state of battery charge, hence a regulator for lamp voltage is needed. A constant-voltage system which is sufficiently practical to keep the batteries charged also requires a lamp regulator. Such a device may comprise a shunt solenoid connected across the lamp load, its core varying the

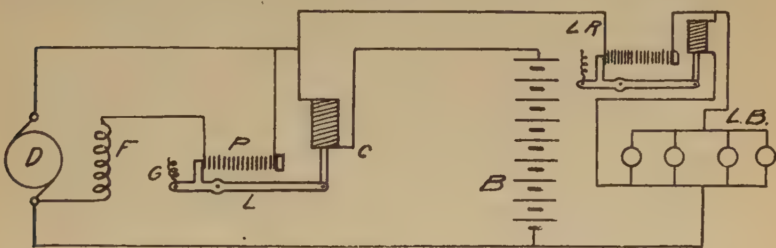


Fig. 4. Generator Connected for Constant-Current Charge to Battery, with Lamp-Voltage Regulator

pressure on carbon blocks in series with the lamps and thus controlling the voltage at the lamps, as shown in Fig 4. at *LR*.

Instead of the solenoid controlling a carbon pile, it may be arranged with a curved segment which rocks back and forth over a grid resistance and varies the field current as necessary; or, as in the earlier form, the solenoid may control the contacts of a small motor field or armature to change the direction of rotation of the motor and thereby have a contact arm mounted on the motor shaft, increasing or decreasing the field resistance as necessary.

Modified Constant-Current Regulation. Sometimes, instead of charging the battery at a constant current, it is desired to limit the generator to a constant-current output; then, instead of connecting the regulator winding in the battery circuit, it is connected so that current taken by the battery and all other translating

devices, the lamps, fans, etc., will pass through the regulating coil. Such an arrangement is shown in Fig. 5 and is employed in connection with what is known as a constant-output equipment.

Sometimes it is desired to have the current flow to the battery modified slightly by the voltage of the battery. As a storage battery charges, its voltage rises, and to maintain a constant flow to the battery it becomes necessary to increase the voltage of the generator. If anything occurs to hold back the rise of the generator voltage as the battery voltage rises, then the rate of charge of the battery is diminished. The rate of charge of a battery may be modified therefore, if the solenoid is provided with a double winding, namely, a series coil carrying the battery current and a voltage coil acted upon by the battery voltage. As the battery voltage rises, the pull of the shunt coil will increase, and this, combined with the pull of the current coil, overcomes that of the

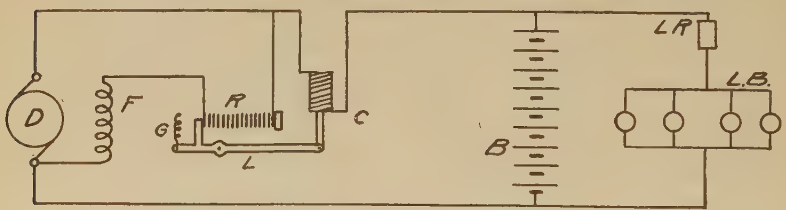


Fig. 5. Generator Connected for Constant-Current Output

balancing spring, and the pressure on the carbon pile is slightly reduced until a new balance obtains at a lower current value. This construction, dependent upon the relative value of the series-coil and the voltage-coil ampere turns, may produce a moderate or a very marked decrease in generator current as the battery approaches full charge. The pull on the solenoid core always requires the same number of ampere turns, therefore if the voltage-coil ampere turns rise, owing to increased battery voltage, the equivalent number is deducted from the series-coil ampere turns, which means less current to the battery. This construction, Fig. 6, is used in the modified constant-current method of charging and also in the modified constant-potential method of charging; the sole difference is that in the one case the number of series ampere turns is rather large, whereas in the second case the series ampere turns are relatively fewer.

Current Regulation Followed by Voltage Regulation. The storage-battery problem is primarily one of maintenance. If a battery is continually charged at the same rate of current (whether it is in a discharged or fully charged state), the life of the positive plates of the battery will be considerably shortened and excessive evaporation of electrolyte is bound to occur. Moreover, operating a battery with low electrolyte reduces its capacity and exposes the plates to the air, which injures the negative plates. Therefore constant-current charge is objectionable.

When a substantially discharged storage battery is charged at a constant potential the flow of the current into the battery is at a very high rate; when the battery approaches a full charge, the flow into the battery is reduced by the rising battery voltage. This would be satisfactory if the battery were always operated

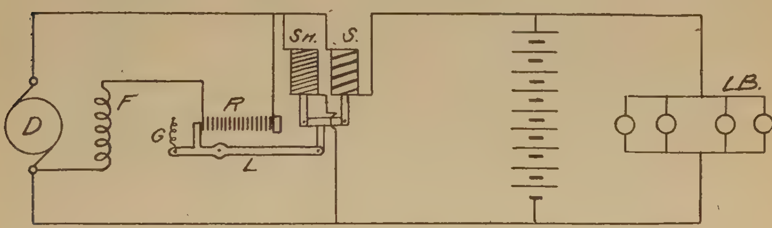


Fig. 6. Generator Provided with Regulator Having Current and Voltage Coils

at the same temperature or were always in a healthy condition. Experience, however, shows that a lead cell with a charging current at the eight-hour rate may, at a normal temperature of 25°C. (77°F.), reach full charge with a voltage of 2.5 volts per cell, whereas at 5°C. (41°F.) it may require 2.75 volts per cell to fully charge it at the eight-hour rate. Lower temperatures require a still higher voltage. Thus an adjustment of the constant-potential system which will suffice to properly charge a storage battery at a normal temperature may fail to charge it at a low temperature, with the result that the battery has not enough charge to meet the lighting demands if the train stands still for a long period. Such a condition may lead to a sulphated battery which, in turn, requires a higher charging voltage than a healthy one, and, therefore, the constant-potential system fails.

The recognition of these conditions as early as 1898 led to the development of an axle-driven train-lighting system, wherein the generator charged the battery at a substantially constant current, independent of the train speed or battery conditions, until the battery voltage reached a predetermined value. This voltage, with the rate of battery charge, represented a substantially charged battery, whereupon a voltage-regulating coil of dominating influence was made active to reduce the generator output to such a value that the battery could not be injured by overcharge. Such a system of generator regulation is shown in Fig. 7, wherein *D* is the generator, *B* the battery, *F* the shunt-field coil, and *R* the regulator. The regulator is provided with two windings *I* and *C*, always in circuit, and a third winding *P*, made effective by a voltage relay *V*, the voltage relay being actuated by the battery

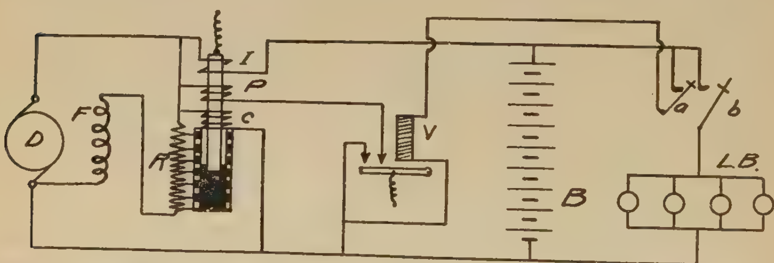


Fig. 7. Early Modified Constant-Current System with Voltage Stop-Charge Relay and Coil

voltage. As the generator in this early system was of limited capacity, the relay *V* was ineffective when lamps were burning, switch *b* being closed and *a* being open. If lamps were not burning, then switch *a* was closed, and when the battery voltage reached the predetermined amount of about 2.4 volts per cell, the relay attracted its armature and connected the coil *P* to the circuit, and the pull of coil *P*, added to that of *C* and *I*, lifted the regulator core, thus increasing the field resistance. The regulator core in this case moved inside a well which was made up of alternate insulating strips and conducting members, the latter being connected to resistance units. As the core was lifted out of the well, the mercury contained therein fell to a lower level and thereby increased the resistance in the field circuit. If the current output fell below the desired value, the solenoid core then fell

lower into the well and raised the mercury level, thereby short-circuiting resistance units.

The principle of this early regulator* has been modified in various ways, as will be described in the discussion of some of the more modern systems.

Regulation by Ampere-Hour Meter. The statement has just been made that voltage in itself may not be a proper indication of the state of battery charge; this may be considered a criticism of the method of stop charge just described. A battery depends upon chemical change to restore it to a charged condition; a certain number of ampere hours must be put back into the battery to produce the necessary chemical change for recharge. If, therefore, an ampere-hour meter is placed in the battery circuit preventing the energizing of the voltage relay *V*, Fig. 7, until a

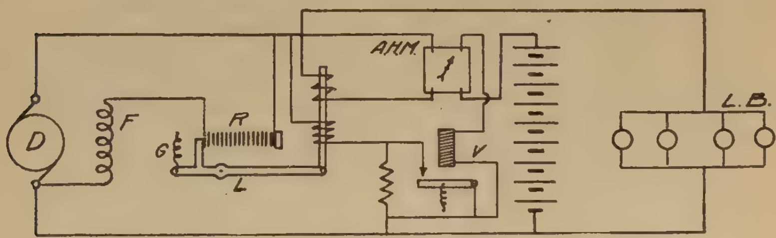


Fig. 8. Modified Current System with Ampere-Hour Meter Control

sufficient number of ampere hours have been put into the battery presumably to recharge it, an additional factor tending to lengthen battery life is provided. Such an arrangement is shown diagrammatically in Fig. 8.† Various systems of train lighting now used employ such ampere-hour meter control as an added element of battery protection.

There are various corporations in this country which have built train-lighting systems based on some one of the principles described. The train-lighting industry, however, up to the present has not been a very profitable venture, so that many companies formerly engaged therein have gone out of existence, although the devices manufactured by them are still encountered. There are,

* Dick Austrian System, B. P. 8179, 1898.
† Kennedy Patent, March, 1912.

however, six or seven standard systems of train lighting used to a greater or lesser degree in present service, and these will be considered in the following pages.

TYPICAL TRAIN-LIGHTING SYSTEMS

CONSOLIDATED RAILWAY ELECTRIC LIGHTING AND EQUIPMENT SYSTEM

Characteristics of System. The Consolidated Railway Electric Lighting and Equipment Company has two general methods of control in use today; one was brought out in 1903 and has

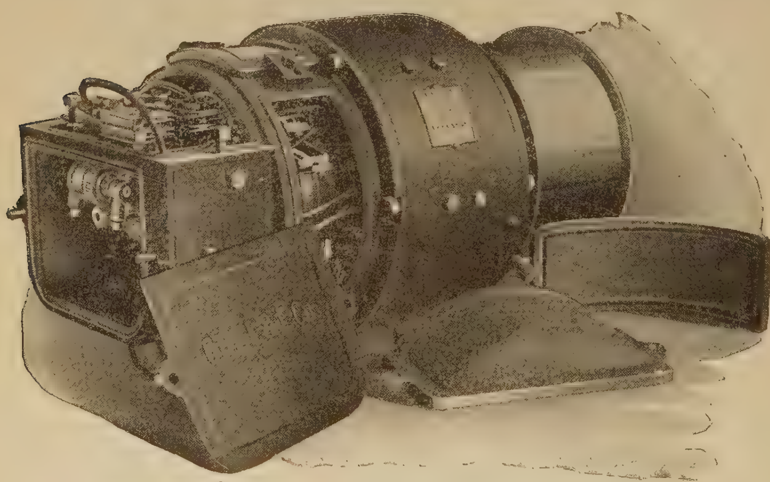


Fig. 9. Typical "Axle Light" Dynamo
Courtesy of Electro Dynamic Company, Bayonne, New Jersey

been widely adopted; the other dates from about 1909 and is gradually replacing the earlier method. In the first system a Kennedy regulator regulates the generator for a constant current; while in the second system a type L regulator regulates the generator so that it furnishes a slightly modified current until the battery is substantially charged, when the ampere-hour meter operates and the voltage coil reduces the output of the generator to a voltage slightly above that of a fully charged normal battery.

Rating. The equipments made by this company are of 2 and 4 kilowatts capacity, and they may be operated at 30, 40, or 80

volts. They are furnished for cars using either 24-, 30-, or 60-volt lamps and with battery equipments of twelve, sixteen, or thirty-two lead cells or twenty, twenty-five, or fifty Edison cells.

Generator. The generator employed by this company is of the interpole type. It is shown with covers off in Fig. 9. The use of the interpole allows the brushes to have a fixed position independent of the direction of rotation, so that no brush-rocking mechanism is necessary to give the brushes proper position for sparkless commutation when the direction of rotation of the gen-

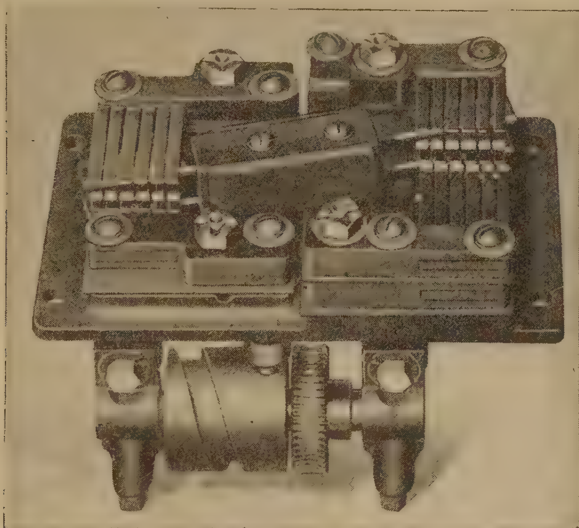


Fig. 10. Pole Changer

erator is changed. Since the generator is used to charge a storage battery, the supply of current must not change in direction, whether the car be traveling forward or backward, necessitating some means to correct the polarity of the generator terminals.

Pole Changer. The pole changer is of the mechanical type and is mounted within the generator housing at the commutator end of the machine, Fig. 9. This pole changer is in effect a double-pole double-throw snap switch, which is actuated by the engagement of a lever pin with an external cam, the latter being rotated by a worm wheel engaging a worm on the end of the

armature shaft. The cam has a spiral groove $\frac{3}{8}$ inch deep across its face for about one-half of its periphery, Fig. 10. Each end of the groove terminates in a slot, gradually rising to the plain surface of the cam. This slot is 90 degrees to the cam axis. It will be seen that when the cam starts rotating in a direction opposite

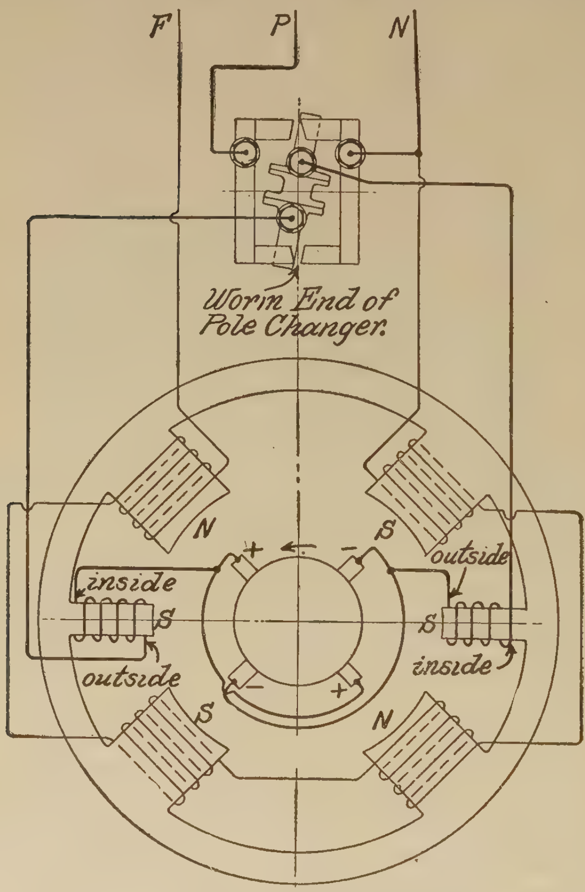


Fig. 11. Connections of Pole Changing Switch

to that just preceding, the pin on the lever will gradually enter the receding slot and, as it touches the side of the spiral groove, it will cause the lever to move through an arc the cord of which is the distance between the centers of the slots, Fig. 10. At the end of the spiral groove the pin will rise as it traverses the ascend-

ing slot and will continue to ride at that end of the cam as long as the machine does not change its direction of rotation. At each revolution of the cam the pin will drop idly into the end slot and ride freely to the surface again. Upon a reversal of rotation the operation of the cam and lever is reversed. The lever is also provided with a spring ratchet which operates at each end of the cam spiral groove to cause the lever to travel approximately $\frac{1}{32}$ inch farther and thereby relieve wear and friction between the pin and the sides of the ascending slots.

As the pivot point of this lever is integral with the pivot of the blades of the switch, the latter will always travel through the same angle as the lever. This angle is sufficient to throw the blades from one contact to another, which corresponds to the reversal of polarity of the generator due to change in rotation. The electrical circuit connection showing how this reversal is accomplished is given in Fig. 11. This illustration also shows that the machine employed has four poles and two interpoles to secure sparkless commutation. The position of the pole-changing switch and the polarities of the armature are shown for counter-clockwise rotation; if the direction of rotation reverses, the polarity of the armature likewise reverses, but as soon as the direction of rotation changes, the switch *S* is moved through a counter-clockwise angle so that the lead *P* will always be connected to the plus terminal of the battery and the lead *N* always connected to the negative terminal.

Suspension. The generator suspension employed by the Consolidated Company is of the two-point swinging type, consisting of forgings extending from the truck end. From these forgings are suspended vertical members supporting a cradle upon which the generator rests. A novel feature of the suspension is the tension device employed, there being an abutment, riveted to the end sill of the truck, against which the tension spring bears. The usual handle nut projects beyond the suspension for the convenience of the inspector in adjusting the belt tension.

Electrical Circuits. Three leads are carried from the generator: one of these, the negative, is common to the battery and the lamps; the positive passes through the automatic switch and series-regulating coil before it reaches the battery and through the lamp-

regulating resistance before it reaches the lamps; the other lead is the positive of the shunt field and passes through the field fuse, the field-regulator resistance, and the generator field before it reaches the negative terminal of the pole-changing switch. This general scheme of connection is common to all "Consolidated" generators.

Kennedy Regulator. The Kennedy regulator is one of the earliest forms of constant-current regulators still in use. It is designed, on the one hand, to maintain the generator current constant at any predetermined value between 20 and 80 amperes

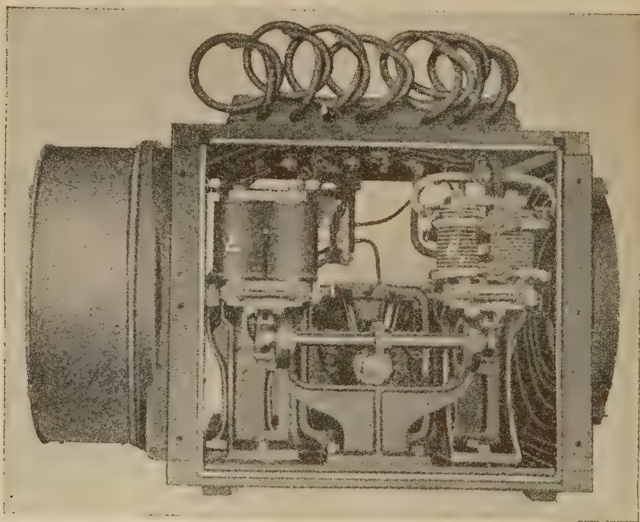


Fig. 12. Kennedy Regulator with Covers Removed

after the generator has reached 20 miles per hour; on the other hand, the regulator acts on the lamp circuit to keep the voltage of the lamps substantially constant, independently of the state of battery charge or lamp load; in fact, it will maintain this voltage, plus or minus one volt, whether the current is supplied from the generator or from the storage battery unless the latter is in a badly discharged condition.

The regulator is contained in a metal case and, when the covers are removed, has the appearance of Fig. 12. At either end of the case are the resistance units. At the left is shown an elec-

tromagnet *E*, which is shunt wound and operates on the lamp-circuit resistance; at the right is a series-wound electromagnet E_1 operating on the field-circuit rheostat. The lamp-voltage regulation and the charging-current regulation are both of the step-by-step method. The operation is described in the following paragraphs.

The circuit connections of a Kennedy regulator are given in Fig. 13; *D* represents the generator; *F*, its field coil; and *M*, the small regulator motor supplied with current from the generator or battery; *S*, the storage battery which is to be charged by the generator; L^1, L^2, and L^3, the lamps to be supplied with current from the generator or the battery or both; *SW*, a hand-operated switch in the lamp circuit; *R*, a rheostat in the lamp circuit, the control brush of which is given the step-by-step motion by action of electromagnet *E; AS*, the automatic switch used to cut in the generator or to disconnect it as it reaches the critical speed; R^1, a rheostat in the field circuit of the generator; and E^1, the electromagnet operating on R^1. The automatic switch *AS* is provided with two windings, one a shunt and the other a series winding. The shunt winding is connected across the generator terminals so as to be acted upon by the generator voltage. This winding is wound upon two soft-iron cores mounted upon a pivoted arm; above these two shunt coils are placed two iron cores with an iron bridge joining them, these being fixed in position. When the voltage of the generator reaches its critical value, about 2.1 volts per cell of battery employed, the magnetism produced by the shunt winding becomes strong enough for the lifting effect to overcome gravity, and the shunt coil with its lever arm is raised so that the circuit is closed between the generator and the battery at the contact *Q;* then, as the generator speed increases, the current flows through the winding of E^1, through the series winding of the automatic switch *AS*, across contact *Q*, and by the wire *d* to the plus side of the battery. The series winding of the automatic switch is such that when the current flows from the generator to the battery its magnetizing effect is in the same direction as that of the shunt winding, and therefore the automatic switch is held closed more firmly. However, if the current flows from the battery to the generator, the magnetizing effect of the series winding opposes that of the shunt coil, and the holding effect of

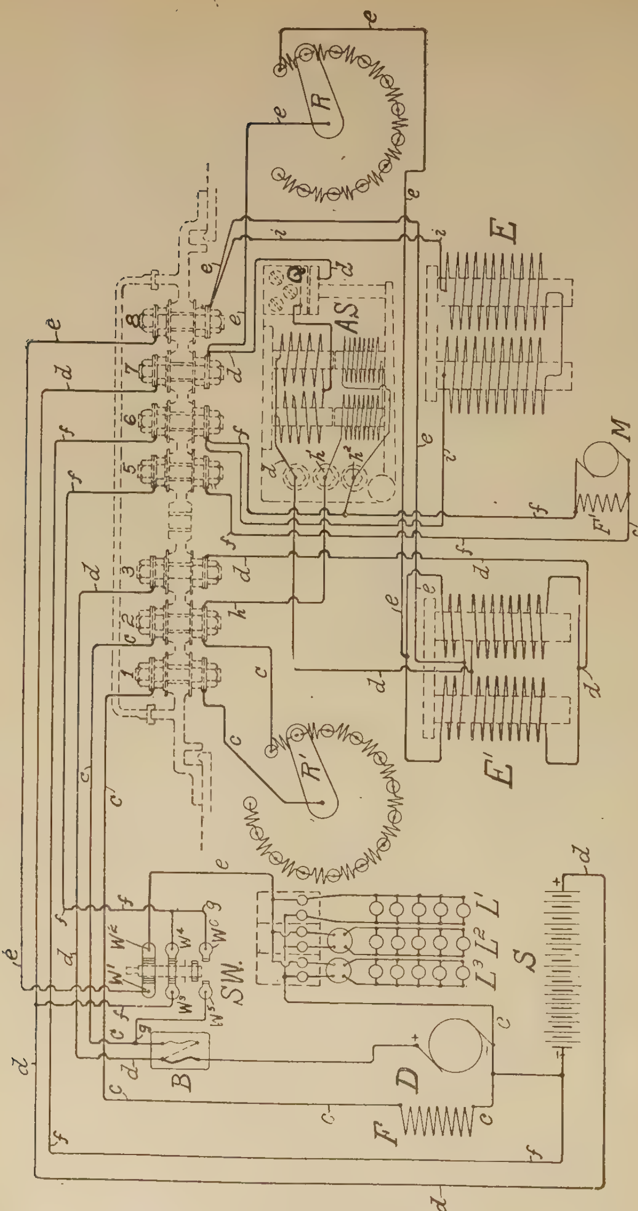


Fig. 13. Wiring Diagram for Kennedy Regulator

the magnet as a whole is decreased, so that the switch falls open and disconnects the battery from the generator, leaving the generator out of the system until the generator voltage is sufficiently high to close the automatic switch again.

A plan of the regulator with the cover removed is shown in Fig. 14, and Fig. 15 is a section through the regulator, giving a view of the lamp regulator magnet *E*, its armature *a*, lever *11*, and lamp-circuit resistance *R*. The small motor *M*, Fig. 14, drives the shaft *6* through the worm *4* and gear *5*. At each end of shaft *6* are two cams. The lamp-end cam *8*, Fig. 15, revolves between two rollers, *15* and *15a*. These rollers are integral with lever *11*, which supports armature *a* and is pivoted at point *w*. On the opposite end the lever *11* carries a double-pointed pawl. The points of this pawl engage ratchet wheels *10* and *10a*, which in turn rotate shaft *9*, carrying the contact arm, or sweep, across the bars of resistance in the lamp circuit. The pull of electromagnet *E* is opposed by main tension spring *18* and balancing tension spring *16*. Upon armature *a* is a projection *20*, which moves vertically between stops *21*.

Upon spring *16* is a small round bar, which rests on stops *21* and only opposes the projection *20* when armature *a* is drawn by the pull of the magnet *E* above the central or balancing point, in which position it is shown in Fig. 15. When a few lamps are turned off or the battery voltage commences to rise, owing to charging, the coil, or magnet, *E* responds to the increased voltage and attracts armature *a* which at the proper time permits roller *15a* on lever *11* to rise into the hollow of the cam and at the same time causes a sufficient lowering of pawl point *12* to engage one tooth of ratchet wheel *10*. As cam *8* is rotating in a clockwise direction, the high point of the cam will force the roller *15a* downward and pawl point *12* upward.

The pawl point, now engaging a ratchet-wheel tooth, will rotate shaft *9* and the resistance sweep in a counterclockwise direction, thereby cutting resistance into the lamp circuit and tending to reduce its voltage and weaken magnet *E*. As the point *8a* in the cam forces the roller *15a* downward, the top roller *15* enters the flat portion *8b* of the cam, but as *8b* passes the roller *15*, it raises the latter slightly, thereby lowering pawl point *12* sufficiently

to permit the spring *14* to again bring the pawl into its neutral position. It will be seen from this that if it were not for the

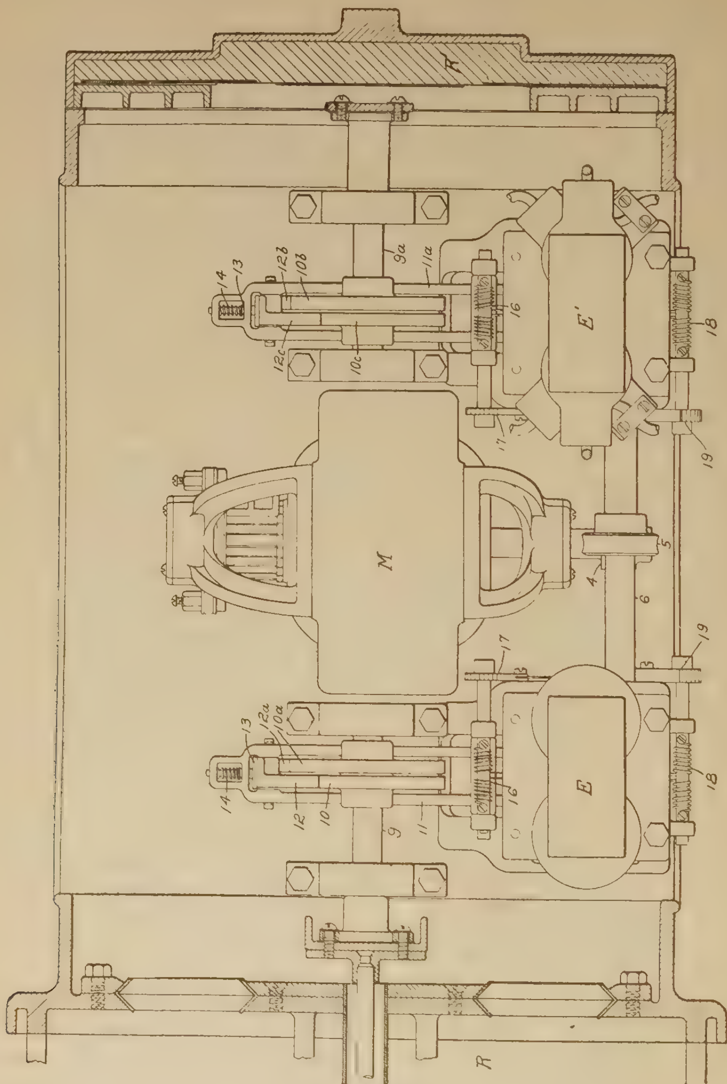


Fig. 14. Plan of Kennedy Regulator

point *8a* on the cam forcing the lever beyond the point required and then permitting it to drop back, the pawl point *12* could not be disengaged from the ratchet wheel. This cycle of operations

continues until the pull of magnet *E* is balanced by springs *16* and *18*.

If the coil at magnet *E* is weakened by reduction in either battery or lamp voltage, spring *18* (not *16*) will at the proper time force roller *15* into the hollow of the cam, thereby raising

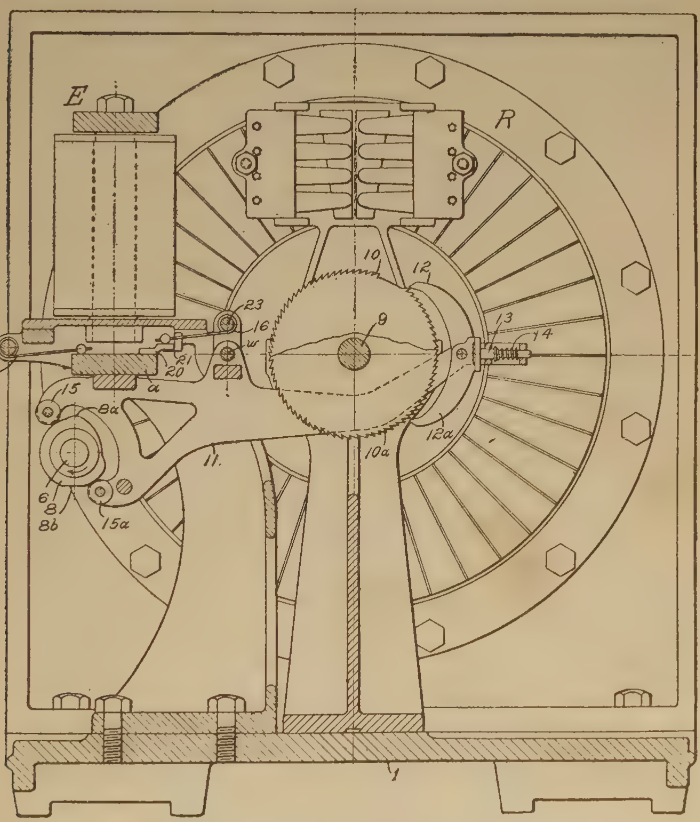


Fig. 15. Section through Kennedy Regulator

pawl point *12a* so that it engages a tooth in ratchet wheel *10a;* and as the rotation of the cam forces roller *15* upward and pawl point *12a* downward and shaft *9* is rotated in a clockwise direction, one step of resistance will be cut out of circuit, which tends to strengthen magnet *E*. This continues until the pull of the magnet equals that of the springs *16* and *18*. Without tension on spring

16 the armature *a* would constantly have a seesaw motion, as it is by applying the extra tension of spring *16* to the upward motion that this effect is eliminated. While spring *18* determines the setting for the lamp voltage, it is spring *16* alone which is adjusted to give the range.

Springs *16* and *18* are provided with shafts and ratchets for increasing or decreasing their tensions. The shafts are interlocked by a screw adjustment having a pointer to indicate on a dial by the side of spring *16* the exact setting for which the regulator will operate. This dial is calibrated, and to change the setting it is merely necessary to turn the adjusting screw until the pointer indicates the desired rate.

As point *8a* on the cam strikes the roller twice every revolution, thereby giving a vibrating motion to lever *11*, it becomes extremely sensitive to the slightest change in voltage.

As already explained, the same principle is employed for regulating the generator field. The magnet *E* of the regulator has two series windings, one in the battery circuit and one in the lamp circuit; these windings are in opposition to each other. The reason for this is that in the daytime, when no lamps are burning, the generator should not give more than the proper current for charging the battery, while at night, when the lamps are turned on, the generator output should increase so that the battery will not be robbed of current. If the bucking winding of the lamp circuit weakens the magnetic effects of the battery winding on the armature of the magnet E^1, Fig. 14, the spring will press the armature downward and the rotating cam will strike the upper roller of the regulating lever arm, causing the lower pawl to engage with the corresponding ratchet and increase the generator current and output by cutting resistance out of the field circuit until the necessary balance obtains. In this manner the generator output is increased by assuming a portion of the connected lamp load. The regulator motor *M*, Fig. 14, is arranged so that it will be in operation at all times as long as the generator is functioning or as long as any of the lamps are burning, whereas if no lights are to burn and the car is standing still, the regulator motor is made inoperative through the switch *SW* breaking the circuit at W^3–W^4, Fig. 13. When the switch is operated to break the circuit at

W^3–W^4, it snaps into the connection W^5–W^6, which is fed from the generator, and provides the motor operation for the generator end of the regulator whenever the generator is running.

This motor form of Kennedy regulator is no longer widely sold (primarily on account of its cost); many hundreds, however, are still in use. It has been criticized as being somewhat noisy—the click of the cams striking the rollers may be heard when the car is standing still. It is also open to the criticism that while the current regulator which operates with simple solenoids can have only two points of failure, the resistance or the coil connections, the motor operator type has additional points where a failure may occur, namely, the motor connections, the motor field, and the motor armature.

Regulator Adjustments. 1. If the battery shows signs of overcharging, noticeable by the softening of the positive plates or by excessive evaporation of the electrolyte, the generator output should be reduced. This may be done by decreasing the tension of springs *16* and *18* on the generator end so that the magnet *E* may have less downward pressure to overcome.

2. If the battery shows signs of undercharge, either through a marked drop in voltage when lamps are burning, by the light-brown appearance of the positive plates, or by an insistent low specific gravity of the electrolyte, the generator output and battery charge should be made greater by increasing the tension of the springs *16* and *18*.

3. If the battery fails to receive charge during a long run, the trouble may be due to any of the following causes: the generator field may be open; the brushes may not make proper contact with the commutator; the field fuse may be blown; or the belt tension may be too slack. These defects may be noted by inspection, or an ammeter may be placed in the circuit *C* at binding post *1*, Fig. 13, and the flow of current to the field noted. Another method of determining whether or not the generator is in good condition is to slip the belt and close the automatic switch by hand, wedge it in place, set the regulator R^1 so that the generator will have full field strength, using the armature-circuit fuse holder as a switch. If the generator is in proper condition, it will motor when the circuit is closed.

4. Sometimes the shunt winding of the automatic switch is open, and then, no matter what the speed of the generator or its voltage, it cannot come into circuit to charge the battery. Voltage measurement across points h^1 and h^2 will indicate the voltage available for the operation of the automatic switch, and if it has the proper value and the automatic switch does not close, the trouble lies in the shunt winding.

5. The failure of the generator to regulate toward constant current may be due to worn-out pawls, ratchets, plungers, cam rollers, or pins, a faulty field rheostat, a weakened spring, or failure of regulating motor *M* to rotate. If the trouble is due to the last-named cause, fluctuations in the brilliancy of the lamps with change in train speed is also apparent.

6. The failure of lamp voltage regulation may be due to any of the defects enumerated in (5) or to an open circuit in the magnet coil *E*.

7. Persistent low lamp brilliancy may also be caused by a defective battery, either sulphated or insufficiently charged. Test the electrolyte by a hydrometer reading.

8. High voltage at lamps, the burning out of the lamps, or the blowing of the field fuse, etc., shows that the battery circuit is open. This may be caused by a broken connection, a cracked jar from which electrolyte has leaked, etc.

Type L Regulator. The type L regulator, which is of the solenoid design, was brought out by the Consolidated Company to meet the prices set by competition and to overcome some of the objections to the Kennedy motor-type regulator; both generator and lamp regulation are accomplished by solenoids. The generator regulator has also been changed so that it is of the modified-current type having both shunt and series coils. The parts of the type L regulator are shown in Figs. 16 and 17, and the circuit connections in Fig. 18. Type L regulators, as shown in these drawings, are provided with a voltage-operated switch or relay to reduce the generator voltage when the battery reaches a full charge and to change the system into one of constant potential should a break occur in the battery circuit. The generator field rheostat is composed of a group of metallic grids connected in series. Contact is made to various points of this resistance through

a series of metallic strips arranged side by side and separated from each other by insulated material constituting a flat commutator-like surface upon which a curved contact piece, built up of leaves of copper, is rocked. These leaves are so assembled and mounted that they bend slightly under the pressure given them and thus acquire a wiping motion which insures good electrical contact and maintains the surface clean; this contact brush is shown clearly in Fig. 16. Examination of Fig. 16 shows that the solenoid core is lifted by current change against the downward pressure of a flat spring *S*. When the core is lifted to more effective positions in the solenoid, the spring strength must increase so that the motion of the core will not be too great. An effective way of accomplishing this is to shorten the flat spring, and the shortening is effected through the agency of the curved surface *C*, against which the spring is moved as the plunger rises. When the plunger is in its lowest position, the curved contact brush rocks to a point close to its support; this cuts out all field resistance. As the plunger progressively rises with the increase of train speed, the point of contact between the rocking brush and the flat surface

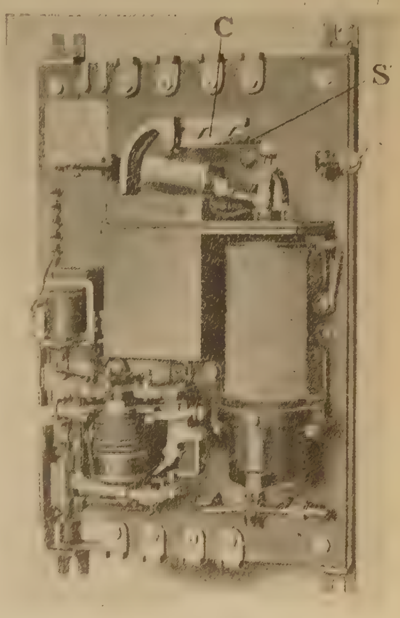


Fig. 16. Type L Dynamo Regulator

of the resistance segments moves gradually to the extreme tip of the brush contact, thereby gradually increasing the resistance in the field circuit. Thus by a limited motion of the solenoid plunger a very large resistance variation may be obtained and the charge rate maintained over a wide speed range. The application of the curved rocker brush has made the metallic grid resistances available for regulation against a wide speed range and has in this particular system eliminated the carbon-pile resistance. In the opinion of the writer, carbon piles are not the most desirable

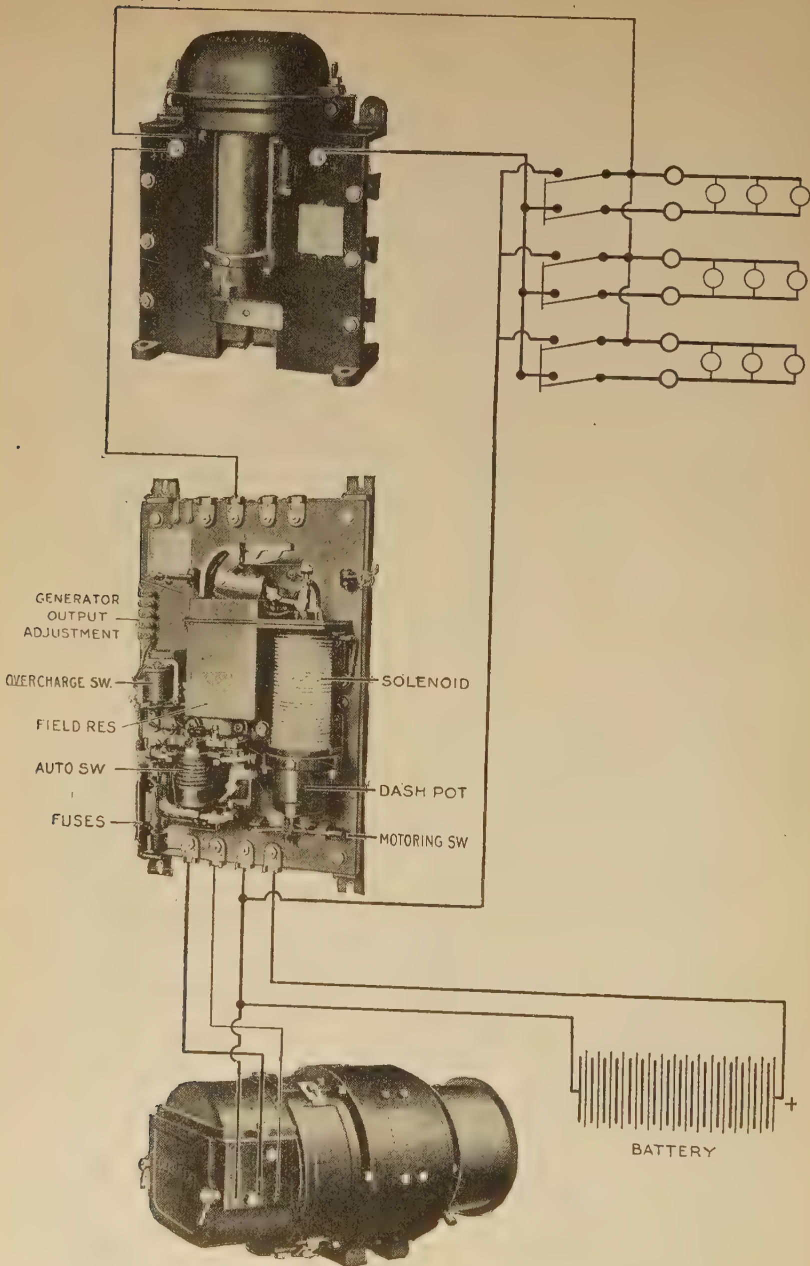


Fig. 17. Arrangement of Parts of Type L Equipment

agents for a railway-train generator or lamp regulators, as the discs must be made thin to be effective and, being fairly brittle, may crack or have their surfaces injured by arcing; still further, even under maximum pressure the carbon pile introduces resistance in its related circuit and thus influences the cut in speed of the generator and range of the lamp regulator. These defects interfere with the effectiveness of carbon piles as resistance members.

Generator Regulator Operating Coil. As seen from Fig. 18, the generator regulator operating coil consists of a solenoid provided with two windings, namely, a voltage coil having an external shunt, and a main winding in series with the generator and the battery. One end of the shunt is connected to the generator, and the other end to the battery lead. For a given setting and with the series coil of sufficient strength to lift its core, the current passing through the coil is always practically constant. If the lamp tap is connected to the point marked *ALL*, the battery will receive its full charge and the generator will carry all the lamp load in addition; if the lamp tap is connected to the point marked *NONE*, the same current will pass through the series as before, but the amount required for the lamps will be deducted from the battery charge. It therefore follows that by connecting the lamp tap to the intermediate points the generator will carry the marked proportional part of the lamp load; the remaining portion, which passes through the series coil, will be deducted from the battery-charging current. Thus, suppose the current through the series coil to be 50 amperes and the lamp load to be 30 amperes. With the lamp tap connected to the *ALL* position the generator furnishes 80 amperes, of which 30 are taken direct by the lamps and the remaining 50 pass through the solenoid, or series, coil and the shunt coil to the battery. With the lamp tap connected at the $\frac{2}{3}$ position the generator furnishes 70 amperes, of which 20 are taken direct by the lamps and the remaining 50 pass through the series coil and the shunt coil as before; but as 10 amperes more are required for the lamps, only 40 amperes are available for the battery.

With the lamp tap at the $\frac{1}{3}$ position the generator will furnish 60 amperes, of which 10 are taken direct by the lamps and the remaining 50 pass through the series and the shunt as before; but

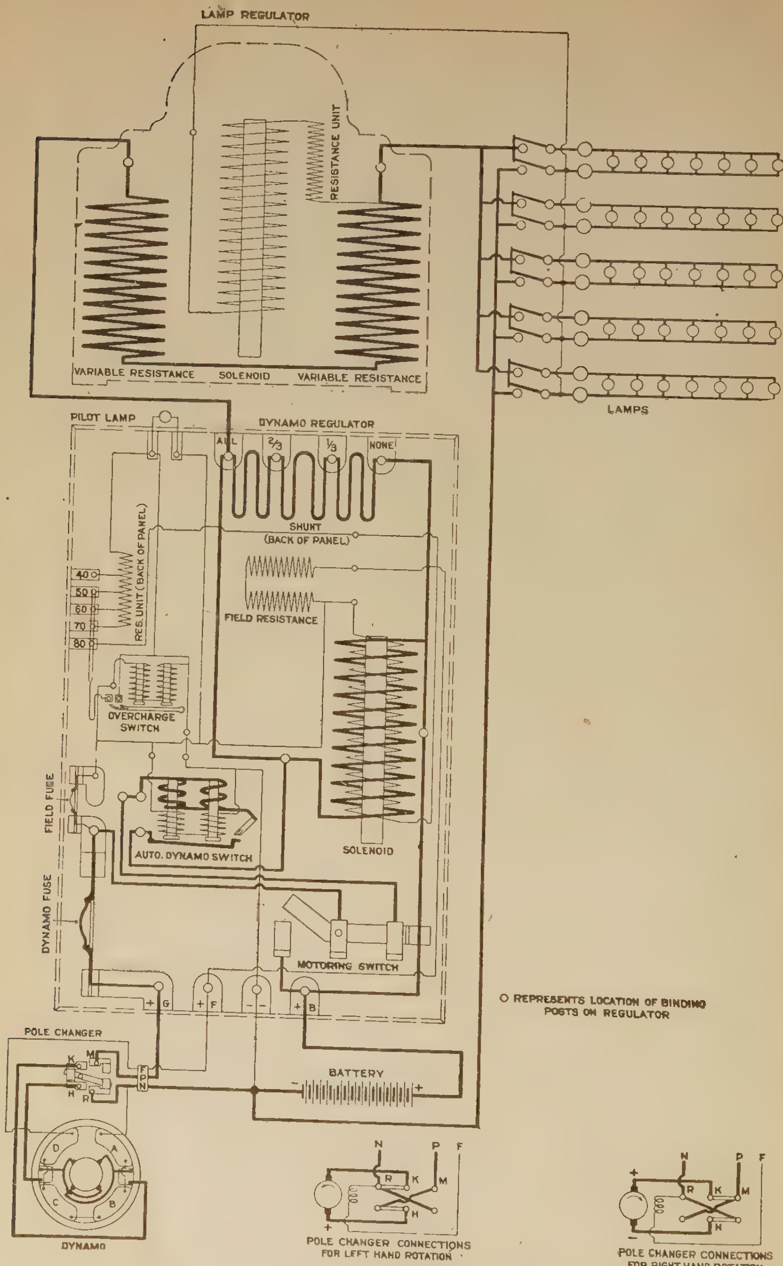


Fig. 18. Connections of Type L Regulator with Stop-Charge Relay

as 20 amperes more are required for the lamps, only 30 amperes are available for the battery.

With the lamp tap at the *NONE* position the generator will furnish 50 amperes, all of which will pass through the series coil and the shunt coil and then divide, 30 amperes going to the lamps and 20 amperes to the battery.

The effect of the voltage coil, shown in fine lines on the solenoid, Fig. 18, is added to that of the series winding and, therefore, as the battery voltage rises, the charging current will taper slightly. In series with the shunt winding of the solenoid is a group of resistance units marked *40*, *50*, *60*, *70*, and *80;* the function of these units is to vary the strength of the shunt winding; as shown in Fig. 18, one resistance unit, namely, *50* to *40*, is not short-circuited. This means that the solenoid as shown is adjusted to regulate to a 50-ampere battery current. If the short-circuiting strip were moved down to *70*, it would mean that the generator is adjusted to a battery current of 70 amperes, and if only the contact at *80* were connected, the shunt, or voltage, coil of the regulator would be open-circuited and the regulator would function as a simple constant-current regulator giving a battery-charging current of 80 amperes or holding the generator to a load of 80 amperes, provided no lamps are burning. Further examination of Fig. 18 shows that the two terminals of the resistance units are led to two contact points of the overcharge switch. When the battery voltage of a sixteen-cell equipment rises to about 40 volts, the overcharge switch attracts its armature and short-circuits the two points before mentioned. This cuts all resistance out of the voltage coil of the regulator and gives it maximum strength; the solenoid core is lifted immediately to increase the resistance in the shunt field of the generator, thus decreasing the current furnished to the battery to a small floating value of about 3 or 4 amperes. The charging curve of the equipment is shown in Fig. 19. The generator, however, remains effective to carry all lamp load.

Lamp Regulator. The lamp regulator is of the solenoid type and has a rocking arm substantially the same as the generator regulator. Its coil is shunt wound and is connected across the lamp load. It therefore responds to variations in voltage of the lamp circuit and reduces the resistance in series with the lamps when

the lamp voltage tends to fall, or increases the resistance if the voltage of the lamp circuit tends to rise by corresponding variation of the *IR* drop.

Automatic Switch. The automatic switch on this regulator is a double-pole electromagnet with a movable armature. The magnet coils of this switch are series and shunt wound so that a discharge from the battery to the generator may cause the automatic switch to open.

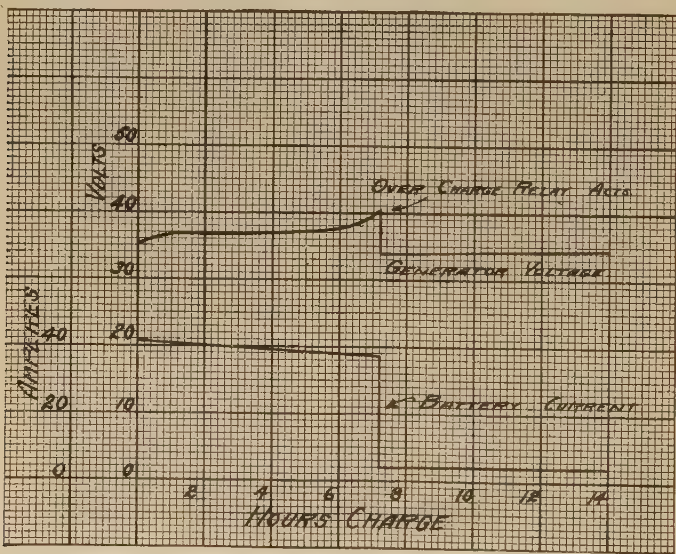


Fig. 19. Characteristic Charging Curve of Modified-Current System with Stop-Charge Relay

Overcharge. The stop-charge switch is connected across the terminals of the generator on the generator side of the automatic switch so that whenever the generator stops rotating or its voltage falls below the proper amount, the overcharge switch will open, resetting the generator regulator to normal output so that charge to the battery will always be at the top rate after every stopping of the train. The stop-charge switch acts to reduce the rate of battery charge when a predetermined voltage obtains by attracting its armature and cutting out the resistance in series with the voltage coil of the generator regulator, thus making the lifting effect of the regulator winding greater, inserting more resistance in the

field circuit, and reducing the generator battery-charge rate to about 3 or 4 amperes. After this, in spite of speed change, the regulation produces substantially constant voltage, unless the train stops, in which case the higher rate is automatically restored as previously explained.

If the battery circuit accidentally opens, the sudden rise in voltage of the generator closes the overcharge switch, thereby permitting the voltage coil of the solenoid to come into control of the system, preventing the voltage from exceeding the maximum charging voltage of the normal system, and also preventing the burning out of lamps and all voltage coils.

Motoring Switch. A switch is placed at the lower right-hand side of the regulator panel, which, when thrown to the left, will motor the generator. This action, however, requires either a very slack belt between the generator and the car axle or none at all. The motor test is made to determine that the machine is in proper running condition. To determine if the clockwise and counterclockwise rotations are alike, reverse the pole-changing switch by rotating the motor armature in either direction until the switch is operated.

With the motoring switch closed, slowly raise the solenoid core until all the field rheostat resistance is in circuit; this will cause the generator to motor at high speed. Then suddenly release the core and it will drop much faster than the motor armature will reduce its speed. As this will give full field to the motor at high speed, its armature will generate sufficient voltage to close the automatic switch; then when the motoring switch is released, the automatic switch will open as under normal conditions. This test checks the correctness of the generator armature, field, field rheostat, and automatic switch.

Ampere-Hour Meter Control. The type L regulator was designed by Mr. P. Kennedy for the application of ampere-hour meter control of the battery charge. Mr. Kennedy applied for United States letters patent for such control in 1908 and was granted them in 1912. As previously explained, the voltage of a battery is not a proper indication of the state of charge because in cold weather the voltage is higher than in warm weather and when the electrolyte is low, the internal resistance is greater than normal and the charging voltage is correspondingly higher. More-

over, if the cell is unhealthy owing to the formation of sulphate on the plates or if a high-resistance connection is in the circuit, the charging voltage is also higher than normal. Consequently, if the charge of a battery were stopped by voltage indication alone, it might well happen that it would be stopped before it was properly completed.

It is one of the essential functions of a train-lighting system to furnish light when the train is standing still, in which case the battery must supply the current. If, however, the battery is not charged, this function of the train-lighting system will not be performed; hence, if the system is to be absolutely reliable, the battery charge should not be stopped by an indication which may be wrong. A definite method of assuming approximately a full charge of the battery before reducing the charge is to take a record of the ampere hours of charge and let a sufficient amount of charge be put into the battery before the voltage indication may become effective. The ampere-hour meter attachment in connection with the stop-charge coil accomplishes this. The connections of the type L regulator as arranged for ampere-hour meter control are shown in Fig. 20. Examination of this drawing, starting from the common negative point of both generator and battery, shows a lead *a* connected to one side of the coil of the overcharge switch, from the other side of which is wire *b* to a resistance unit *c*, and from this the circuit passes by the wire *d* to the positive side of the generator at the generator side of the automatic switch. From the ends of the resistance *c* are leads *e* and *f* to a small contact *g* inside the ampere-hour meter. The ampere-hour meter records both charge and discharge of the battery. When the large dial hand (the indicator of the state of battery discharge) gets back to zero, it indicates that the battery has received its full charge in ampere hours and at the same moment this hand closes the contact between the wires *e* and *f* at *g*, thus shunting the resistance unit *c*. Before the short-circuiting of the resistance unit *c* the overcharge switch will not have sufficient current passing through it to attract its armature, even though the line voltage may be as high as 49 volts. When the resistance *c* is short-circuited, the overcharge switch will have sufficient current through its windings, provided the voltage desired at the

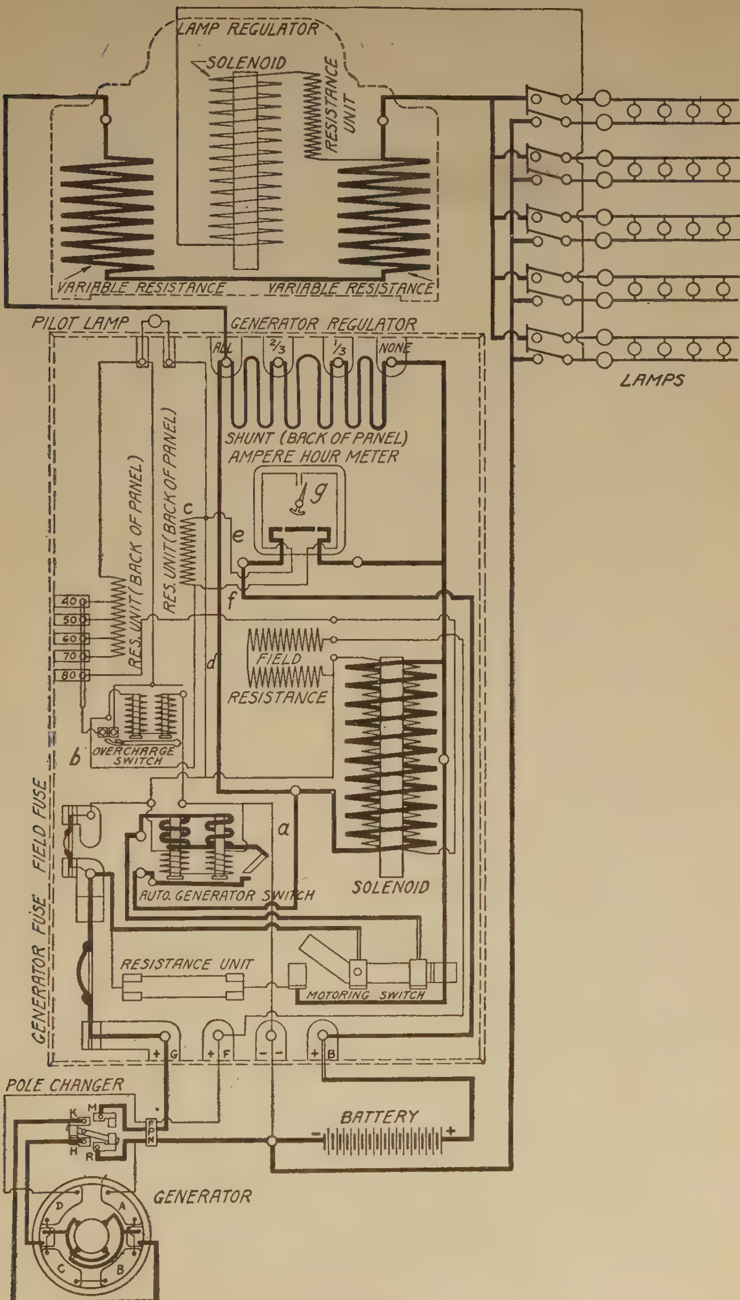


Fig. 20. Connections of Type L Regulator with Ampere-Hour Meter Control

battery terminals exists, to attract its armature and short-circuit the resistances in series with the potential coil of the regulator, after which the equipment will float at about 36 volts. It is to be noted that after the ampere-hour meter has returned to zero and closed the contact *g*, the overcharge switch will not close unless the battery voltage has reached some predetermined value, which value is fixed by the distance between the poles of the overcharge switch and its armature. This voltage may be 40 volts or any other value at which it is desired to operate, but until the overcharge switch does close, the battery will charge at the normal rate. In this way the combination of the ampere-hour meter and the switch adjustment compensates for irregularities in the ampere-hour efficiency of the battery and keeps the meter in step with the state of charge of the battery. To compensate for the errors in the ampere-hour efficiency of the battery, the Sangamo ampere-hour meter, which is used with this ampere-hour meter system, as well as in other systems, is made to move slower on charge than it does on discharge. The average ampere-hour efficiency of lead batteries as used in train lighting work is about 80 per cent; hence the meter is set so that it will run about 25 per cent slower on charge than on discharge. If this percentage of efficiency is not correct, no very large error can be introduced because of the protection of the voltage stop-charge coil; therefore if the battery is slightly overcharged, by the time the ampere-hour meter indicator reaches the zero point, the battery charge would be immediately stopped, as the voltage would have reached the predetermined point; or, if the battery is slightly undercharged by the time the ampere-hour meter gets to zero discharge indication, the charge will continue until the desired voltage is obtained.

The principles and care of the Sangamo ampere-hour meter will be considered later.

Regulator Adjustments. 1. The regulator may get out of adjustment by the flat spring *S*, Fig. 16, becoming fatigued, though such a condition is not likely to obtain, as all tension is removed from the generator-regulator spring when the train is not under way and from the lamp-regulator spring when no lamps are in use. In case spring failure interferes with the regu-

lation, secure a new spring from the manufacturer. If, however, the spring is in good condition, the regulator may be adjusted by loosening the lock nut and turning the thumbscrew on the threaded stud in the link connecting the spring to the solenoid core. Lowering the thumbscrew one turn will decrease the generator current by about 1 ampere; raising the screw one turn will correspondingly increase the generator current. After the adjustment has been made, secure the lock nut firmly.

2. If the battery shows signs of overcharge such as soft positive plates or excessive evaporation of electrolyte, the factor of ampere-hour meter correction is too high. This may be corrected by changing the setting of the resistor of the ampere-hour meter so that it will travel somewhat faster on recharge; or the charging current may be reduced by short-circuiting more of the resistance in series with the potential coil of the regulator. Failure of the stop charge relay due to poor contacts in the meter or a break in the coil connections may also cause overcharge.

3. If the battery shows signs of undercharge, the charging current may be too low, or there may be a leak around the battery. Thoroughly clean this, and see that there are no grounds between the cells and none on the battery leads.

4. If a battery is badly sulphated at the time it is installed on the train, it will in all probability remain so because an overcharge is not possible; hence, if a battery is found to be in a persistently discharged condition, giving low specific gravity readings, it is advisable to remove the battery for treatment, because if even as much as 20 per cent more ampere hours are put into the battery on charge than are taken out on discharge, this will not suffice to eliminate the sulphation, because the stop-charge switch will immediately cut down the rate at the completion of charge. The only way to restore a sulphated battery on a coach would be to wedge the stop-charge switch open; this, however, is not advisable unless done upon written directions of the master electrician, as the stop-charge switch should not be tampered with.

5. Persistent high voltage at the lamps with excessive motion of the lamp regulator indicates an open circuit of the battery line.

6. All train-lighting systems have a pilot lamp which glows when the train-lighting system is functioning. Failure of the lamp

to glow at all indicates that the generator has not sufficient voltage to close the automatic switch. The failure may be due to the defects noted in paragraphs 3 and 4 above.

7. Persistent dimness of the lamps may be due to the fatiguing of spring *S* on the lamp regulator. As a result the rocking brush fails to short-circuit all the resistance when the car is standing, and more than sufficient resistance is inserted into the circuit while the car is running. Again, dimness of the lamps may be caused by the loss of some pin on the spring. This would allow a low voltage to lift the solenoid core to such a position that too much resistance would be in the lamp circuit.

SAFETY CAR HEATING AND LIGHTING SYSTEM

The Safety Car Heating and Lighting Company has developed different forms of train-lighting systems, but its present standard form is known as the Safety type F regulator.

Rating. The generators employed by the company are four-pole shunt-wound machines and are designed for high speed. They have a capacity of 1, 3, and 4 kilowatts, respectively, and are designed for standard train-lighting voltages. The appearance of the generator in section is shown in Fig. 21.

Generator Suspension. The generator with its suspension is shown in Fig. 22. Cast upon the frame are carrying lugs, which are pivoted upon the suspension carriage by the suspension bearing pin. The suspension carriage is designed to be bolted to a suitable plate secured to the underframe of the car, and the belt tension is maintained by the weight of the generator and by the tension spring, which engages at one end with a lug on the generator frame and at the other end with a bracket secured to the suspension carriage. The parts are designed so that the sum of the two varying tension forces is constant. When the generator is hanging so that the center of gravity is directly under the suspension bearing pin, as illustrated in Fig. 22, its weight adds nothing to the tension on the belt, all of the tension being caused by the spring. If the generator swings forward toward the driving pulley, the weight of the generator will act to give some tension; but the lever arm of the spring has been diminished in length, and hence its effect has been reduced. The sum of the

two forces acting on the belt will remain the same; thus the variation in distance between the generator axle and the car axle

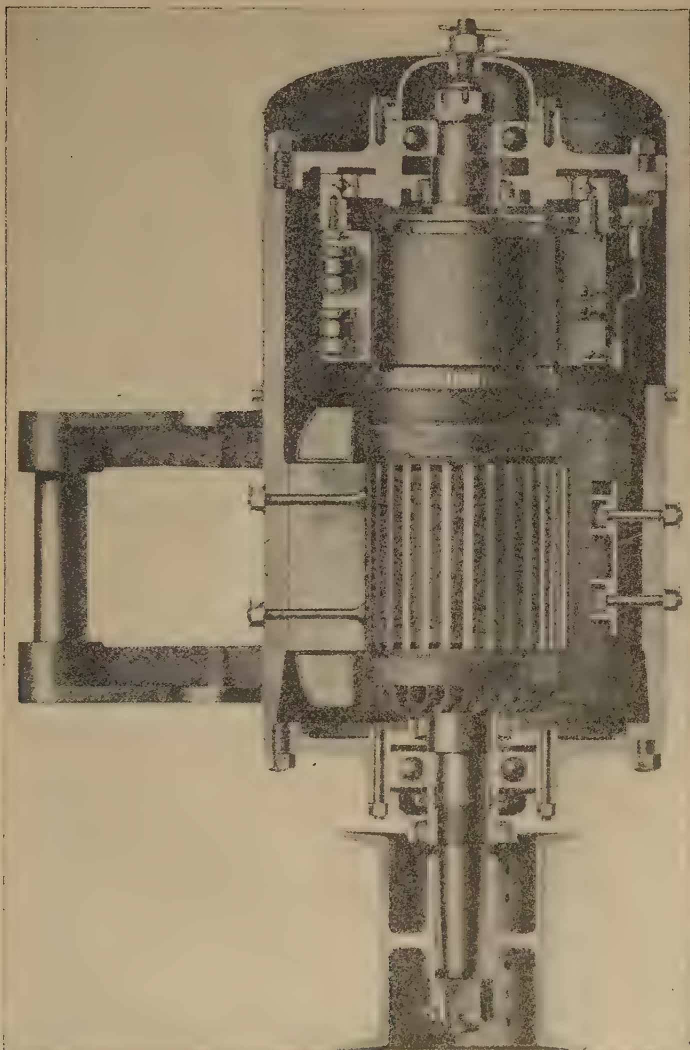


Fig. 21. Sectional View of Underframe Generator
Courtesy of Safety Car Heating and Lighting Company, New York

on a curved track is taken care of. The introduction of a balancing feature of this sort is necessary because the generator is not carried by the truck.

If it is desired to slip off the belt from this equipment, a pipe lever may be put over a projecting stud on the frame; by

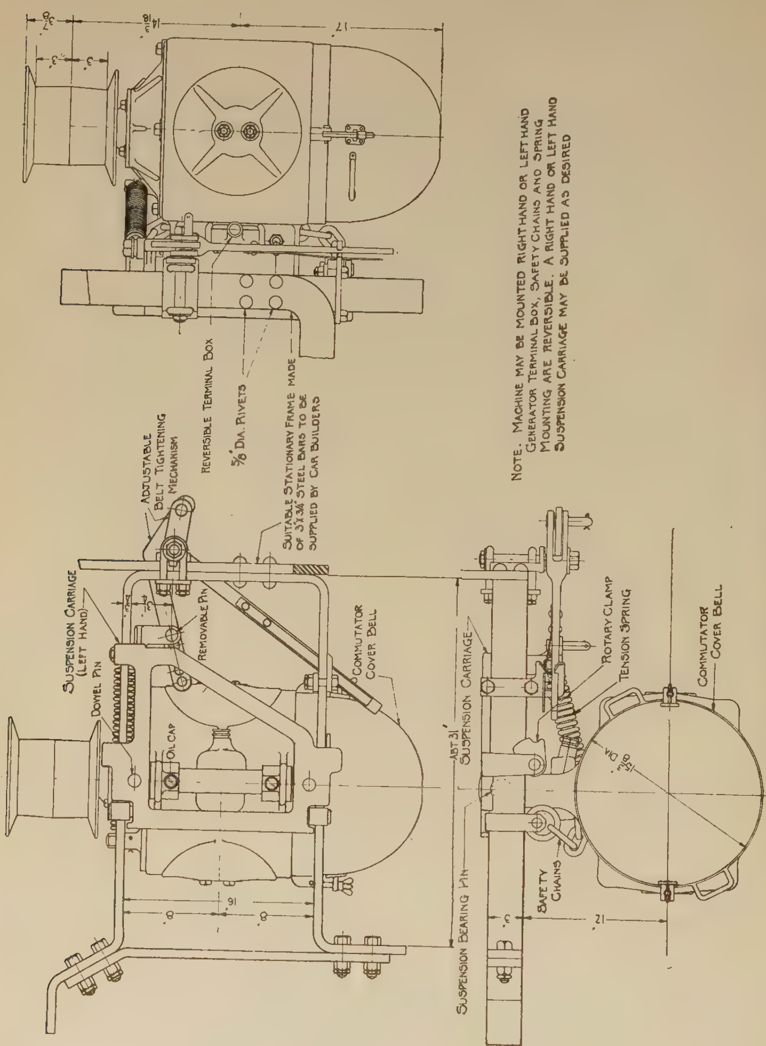


Fig. 22. Diagrams of Underframe Generator Showing Method of Suspension

pressing down on it the generator may be swung toward the truck so as to slacken off the belt.

Pole Changer. Since the generator may rotate in either direction, depending upon the direction of travel of the coach, means

must be introduced to correct the polarity of the armature for change in direction of rotation; this is accomplished by rotating the brushes through an angle of 90 degrees. The brush holders are mounted upon a ball-bearing sleeve, the friction between the commutator and the brushes being sufficient to rotate them through the necessary angle; stops are employed to limit the motion. The ball bearings for this purpose are located in the rectangular notch shown at the right of the brush studs.

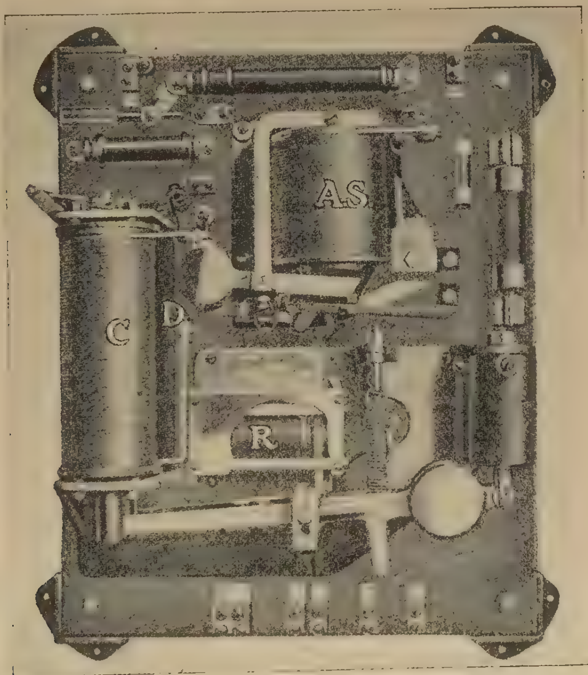


Fig. 23. Safety Type F Dynamo Regulator

Regulator. The dynamo regulator is of a modified-current type in that it employs the combined effects of a current-regulating coil and a voltage coil. These coils are wound upon separate forms and act upon separate cores; their coaction is obtained through the inter-connection of their levers and the common return path of their magnetic circuits. The current-coil lever has an inwardly projecting finger upon which rests an outwardly projecting finger of the voltage-coil lever, and the voltage-

coil lever is provided with a finger which presses upon the carbon pile. Each lever has its independent spring by which its balanced

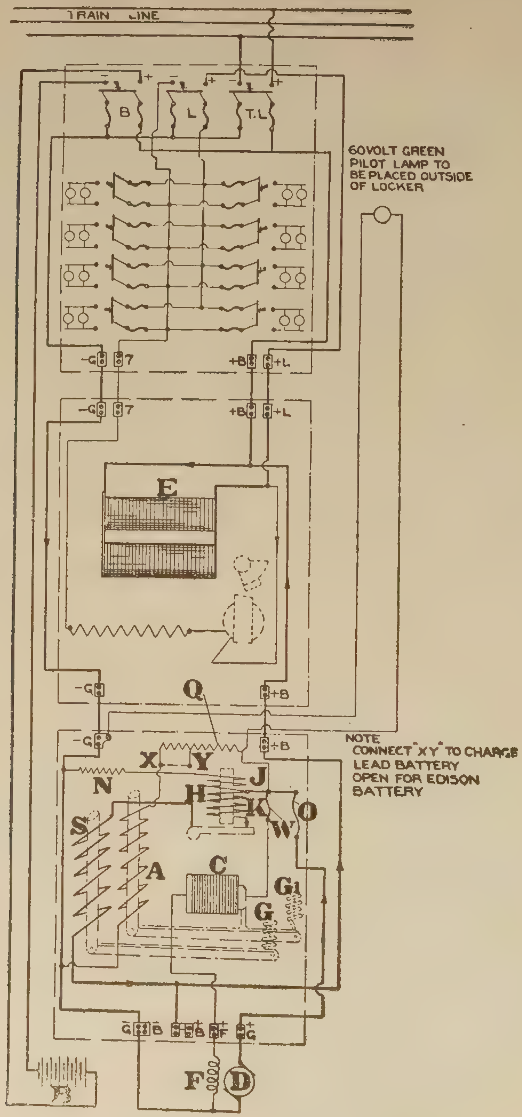


Fig. 24. Wiring Diagram of 40-Volt Type F Regulator

position may be adjusted. The generator-regulator panel is shown in Fig. 23, which illustrates clearly the current coil *C*; the voltage

coil D; the carbon pile R, controlled by the regulator; the automatic switch $A.S.$, and the adjusting resistances. The circuit connections of the regulator are shown in Fig. 24. The three leads from the generator are connected respectively to $G+$, $F+$ and $G-$. From $F+$ the circuit is through the carbon-pile rheostat C through the generator side of the automatic switch, where the field circuit is connected to the positive-potential side of the generator. The plus side of the generator is connected to the series coil of the automatic switch at K, thence through the contact of the switch, through the series coil S of the regulator, from which it passes to the positive terminal of the battery branch and thence through the lamp-regulator resistance E to the positive side of the lamp load. The negative terminal of the generator is connected to the negative terminal of the battery and the negative terminal of the lamp load. Connected across the generator terminals, in series with an adjustable resistance Q, is the voltage coil of the regulator. Connected across the generator terminals in a similar manner is also the voltage coil of the automatic switch. The operation of the regulator is as follows:

The automatic switch closes after the train has reached its critical speed—about 20 miles an hour—and is generating substantially 35 volts. As the train speed is further accelerated, the charging current to the battery rises and as it reaches a value of whatever the regulator is adjusted for, say 62 amperes, the current coil lifts its plunger, and its lever finger comes in contact with the finger of the voltage-coil lever. If the battery is only partially charged, then the lifting effect of the current coil must help the voltage coil before the pressure on the carbon pile C of the shunt-field circuit can be reduced. This means that the current in the series coil and therefore the generator output must be at or near the maximum. However, as the battery state of charge is increased, the voltage of the battery gradually rises, and the potential coil will more and more tend to overcome its own spring force with a consequent gradual tapering off of the current flowing to the battery, because the current coil need not exercise so much of a lifting effect as when the battery voltage is low. It is during this stage that the Safety type F regulator is of the modified-current type. However, when the battery voltage has

finally risen to a predetermined amount, substantially 39 volts, the voltage coil is sufficiently powerful to act against its own spring and its lever is moved forward and backward to vary the pressure on the carbon pile mechanically, independently of the current regulator, whose inwardly projecting finger is no longer in contact with that of the outwardly projecting finger of the lever of the voltage coil; and at this point the modified constant-voltage regulation supersedes the modified-current regulation, and the current flowing to the battery on charge tapers off rapidly, as shown in Fig. 25. The magnetic circuits of the volt-

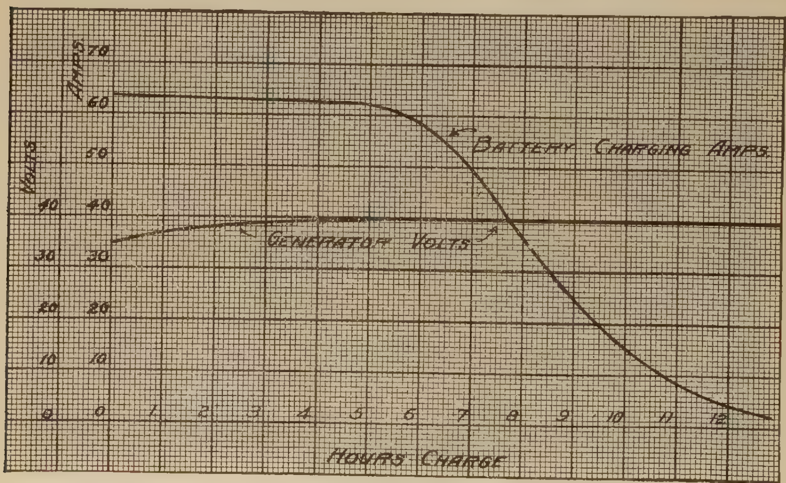


Fig. 25. Battery Charging Characteristics of Safety Type F Regulator

age and current solenoids are, however, interrelated, and as the current in the current coil gradually decreases, the voltage-coil pull also slightly decreases, and there is a marked taper in the current. Owing to the fact that the potential-regulating coil is connected to the generator side of the automatic switch, every time the generator voltage falls to such a point that the automatic switch is opened, modified-current control is reintroduced, even if only momentarily, as the speed of the train is again accelerated.

The lamp regulator which is utilized with this generator regulator is of the shunt type and has its coil connected directly

across the lamp leads. The resistance in series with the lamps comprises two carbon piles, the pressure on which is varied by the armature of the shunt regulator inversely as the voltage of the system. The construction of the lamp regulation is shown in Fig. 26.

Adjustment of Generator Regulator. The voltage coil *A* of the regulator, Fig. 24, is adjusted at the factory, so that it is

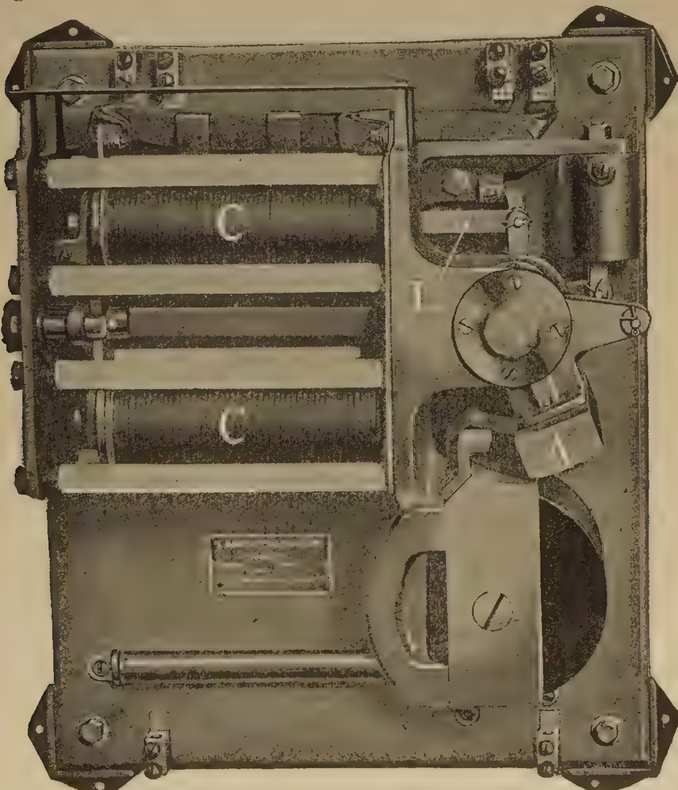


Fig. 26. Safety Type F Lamp Regulator

fully effective at 39 volts with 30-volt equipments and at 78 volts with 60-volt outfits, respectively. When Edison cells are used, this voltage is raised to 43 and 86 volts, respectively, by removing the shunt *X Y* from the resistance *Q*. To check the setting of the voltage coil *A*, place a piece of insulating material between the contacts of the main switch *M*, then no current can

pass through the current coil S and the stop on its plunger rests against the top of the coil head. Then if the car is run at a speed of 30 miles an hour or over, the voltage across the generator terminals should be 39 volts with a sixteen-cell lead-battery equipment, 78 volts with a thirty-two-cell lead-battery equipment and 43 volts or 86 volts with Edison-cell equipments of twenty-five or fifty cells, respectively. If the given voltages do not obtain, adjustment of the spring G^1 connected to the lever of the voltage coil should be undertaken. This may be accomplished by means of the nuts on the supporting stem of the spring. To check the setting of the current coil, connect in an ammeter at the $G-$ terminal of the regulator; if the stop on the plunger guide of the current coil is lifted from the head of the coil, the ammeter will show at what current the coil is regulating. If the stop is against the coil head, compress the field carbon C by hand through the voltage-coil lever and note at what current the series coil regulates. This value of current should be within the rating of the machine; if it is below the machine rating, it may be brought up by increasing the tension of spring G; if it is above the machine rating, it may be brought down by decreasing the tension of spring G.

The relative adjustment of the springs G and G^1 should be such that when the car is standing still and the carbons are tightly compressed by the voltage-coil lever, it is just possible to slip a gage $\frac{1}{64}$ inch thick between the projecting fingers of the levers—a field carbon disc has this thickness.

Adjustment of the Automatic Switch. The main switch is set at normal to close at 34 volts and 68 volts on 30- and 60-volt equipments, respectively, and should not require adjustment in service; however, if it does, raising or lowering the pin which bears upon the armature of the automatic switch to the left of the pivot may serve to obtain the desired setting. Raising the pin increases the voltage necessary to close the automatic switch; lowering the pin decreases the voltage required.

Additional voltage is required to adjust the regulator potential coil when the car is *standing still*, because the battery voltage itself is not of high enough value. This higher value may be obtained by placing a second battery in series with the car

battery so that on 30-volt systems a voltage of at least 42 would be available; or, if a 12-volt portable battery is not available, the battery of a companion car and the car battery itself may be placed in series. Referring to Fig. 27, proceed as follows: Open switch *T.L.* and connect the extra battery across the points marked + and −; then, by means of a jumper, connect the minus terminal of the jaw of the switch to the positive blade and connect carbon resistance *R* between the plus terminal of switch *T.L.* and the top clip of the generator fuse, having first removed the fuse *O*. Now, as the negative terminal of the voltage coil *A* is connected to the negative terminal of the battery with the switch *B* closed, the batteries are placed in series, and their combined voltage may be impressed upon the voltage coil *A* of the regulator and the voltage coil *J* of the automatic switch. Connect, as shown, a voltmeter to measure the voltage across the coil *A* and its resistance *Q*, adjust the pressure on the resistance *R* until the voltmeter indicates the desired 39 volts; adjust G^1 until the plunger stop floats about $\frac{1}{4}$ inch above the top of the coil, then decreases the voltage by varying the small resistance *R* until the plunger moves downward, so that it is influenced by the cushioning effect of the carbon pile *C*, this minimum voltage being about 36 volts.

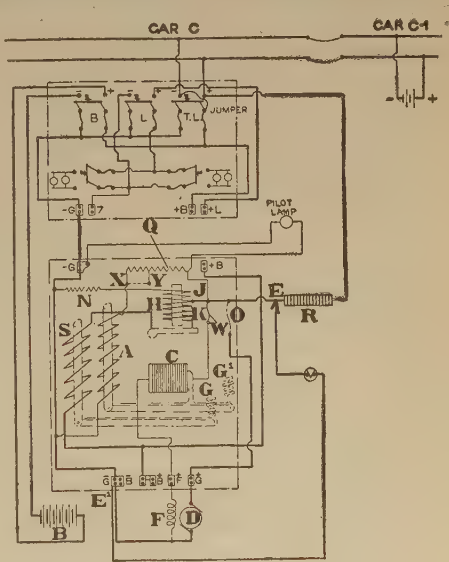


Fig. 27. Wiring Diagram for Yard Testing

The automatic switch *H* may be adjusted by the use of the connections just considered. Proceed as follows: Reduce the pressure on *R* until the voltage read across EE^1 is less than 30 volts, then bring up the pressure on *R* and note if the automatic switch closes when the indication of the voltmeter is 34 volts. If it does not, adjust the pin screw of the automatic

switch until it will close at 34 volts upon gradual increase of the voltage.

Causes of Failure of Regulator. If a battery shows persistent undercharge indications, such as low voltage or low specific gravity, the equipment does not work properly. This condition may be brought about by the following causes:

1. Failure to charge at all may be due to an open main fuse, an open field fuse, or an open circuit in the automatic switch. Charging intermittently may be due to a weakened spring of the voltage coil which allows the modified constant-potential regulation to obtain at too low a value or to obtain too soon. Poor connection in the battery circuit or electrolyte which has spilled owing to a cracked jar will cause the same trouble. Trouble may also be due to high resistance in the carbon pile *C*. This should be examined for broken or cracked discs or foreign matter between the discs.

2. Undercharge may also result if the spring *G* of the current coil is too weak.

3. Brushes out of position, a dirty commutator, or a loose belt may be contributing causes of undercharge.

4. Grounds around a battery, and defective wiring causing leaks of current are also conducive to undercharge.

5. Overcharge may result if the spring of the voltage coil is too strong, which would require a high voltage to change the charge from the modified-current to the modified constant-potential type. A break in the voltage-coil circuit will also cause this battery overcharge, because not only will the system become a constant-current system but it will be of a higher rate than normal, because the current coil then will have to overcome the pull of springs G and G^1 both.

6. If the regulator is sluggish in its motion, examine the vents in the dashpots connected to both current and voltage levers. The sluggishness may be caused by the vent being too much stopped up; by broken bearings or corroded bearings at the upper and lower pivots of the plungers; or by the set screws which act as the pivots for the lower levers being drawn up too tight. The regulator should be examined for these conditions.

7. If the regulators produce a hunting effect, the trouble may be caused by too free an opening in the air dashpots.

8. If the lamp voltage varies appreciably with change in train speed or in the number of lamps connected, the lamp-regulator solenoid may be open-circuited, its dashpot vent may be too tightly closed, or its armature supports may be broken.

9. Lamp voltage may be too low and not regulating. This may be caused by a break in the lamp-regulator spring or its sticking in the top voltage position.

GOULD COUPLER AXLE LIGHTING SYSTEM

The Gould Coupler Company has developed various types of train-lighting systems; the most prominent form and the com-

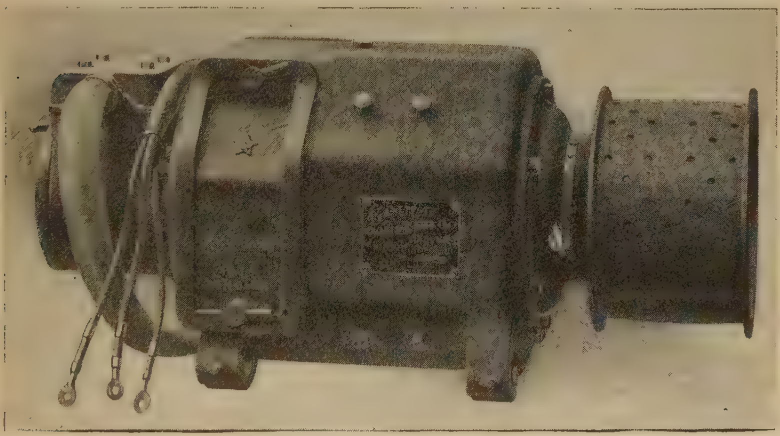


Fig. 28. Gould Train-Lighting Generator
Courtesy of Gould Electric Car Lighting System, Depew, New York

pany's present standard design is known as the Gould Simplex System, of which several modifications are in service.

Generator. The generators employed with the Gould Simplex equipment are simple, shunt wound, and of varying capacity depending upon service requirements. Their general appearance is as shown in Fig. 28.

Rating. The standard sizes are 2, 3, and 4 kilowatts in 30- and 60-volt equipments. The machines are driven at a 2 or 2.5 speed ratio. The drive may be by means of a belt or a flexible chain. The generators are provided with bronze or ball bearings as desired.

Suspension. The Gould Coupler Company employs *drop-type* and *link-type truck suspension* and *car-body suspension;* the same type of generator is available for any of these forms. Link-type

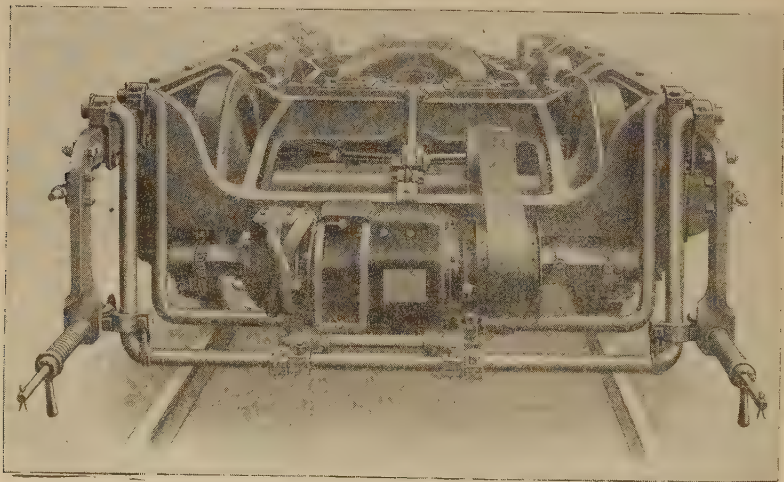
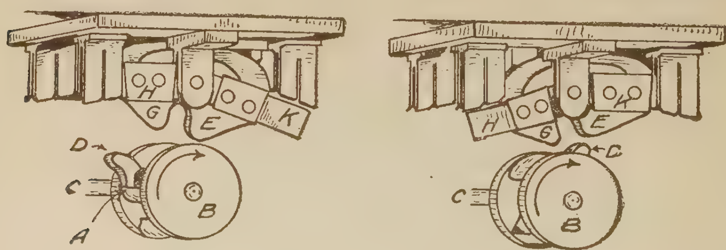


Fig. 29. Gould Coupler Link-Type Truck Suspension

suspension is shown in Fig. 29. It is provided with two springs for belt-tension adjustment, and the cradle carrying the generator is compound, being made of two pivoted pipe forms. Body suspension is somewhat similar to that shown in Fig. 22; it employs, however, a crossbar as a support instead of the plate and an



Figs. 30 and 31. Arrangement of Gould Mechanical Pole Changer

adapter to fit the standard truck type of generator for body suspension

Pole Changer. Like all axle-driven equipments, the generator must be provided with a pole changer to correct for change in

direction of travel of the coach and in this way maintain the polarity of the system independent of direction of generator rotation. The pole changer employed in the Gould equipment is a very interesting one, and is positive in its action. The pole changer comprises a double-pole, double-throw, toggle-spring switch, Fig. 30, placed between the armature leads and the termi-

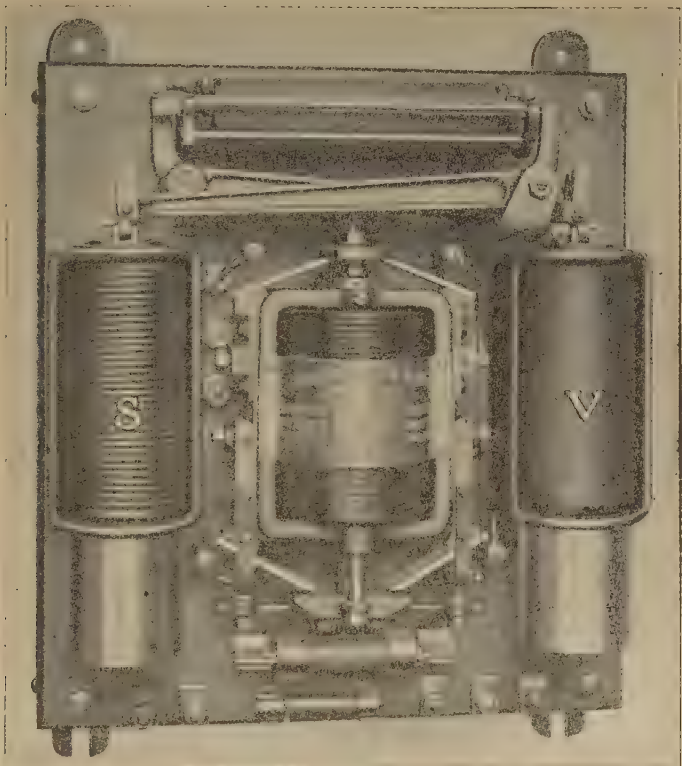


Fig. 32. Gould Simplex Regulator Panel, Type BB

nal board of the generator. It is located at the commutator end of the machine inside a suitable housing. The switch-throwing mechanism, Fig. 30, comprises an eccentrically drilled weight A, pivotally mounted on a carrier B, and secured to the generator shaft C. Projecting lugs from the weight are designed to engage corresponding lugs of the switch. The operation is explained by

Figs. 30 and 31. For example, as the generator starts to revolve in a clockwise direction, the lug *D* of the pivoted weight strikes the lug *E* of the switch, throws blades *H* out of their jaws, and carries the switch over its center. Then the toggle springs snap blades *K* into position, carrying the lug *E* clear of the lug *D*, Fig. 31. As the train speeds up, the weight balances and its

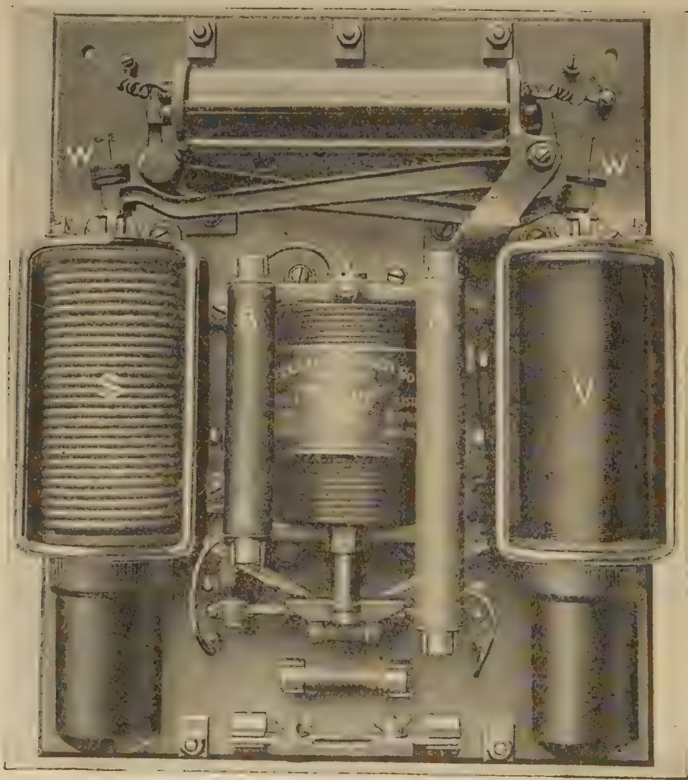


Fig. 33. Generator Regulator Panel, Type BB-9

lugs are in non-engaging positions. When the train slows down and reverses the action, the other lug of the pivoted weight engages the projecting lug *G*, forces the blades *K* out of their jaws, and carries the switch over its center. Then the toggle springs snap the blades *H* into their jaws. This last step clears the lug *G* from co-functioning with the lug of the pivoted weight. The armature brush leads are connected to the middle points of

the double-throw switch; the jaws are cross-connected, and the positive field terminal is connected to the positive terminal of the switch. Three leads come out of the generator terminal board, the main leads and the negative-field lead. This latter is carried to terminal block 3 on the regulator panel, Fig. 35, and thence through the carbon block field resistance to the negative side of the generator. The generator main leads are carried to terminal blocks 1 and 2 of the regulator panel.

Regulation. The generator regulator of the Simplex type is made up in various models, BB, Fig. 32 being the simplest while BB-9, Fig. 33, is substantially the same as the former, but temperature compensation of the shunt coils is introduced by the resistance coils shown at A and B in series with the voltage coil of the regulator and the automatic switch voltage coil respectively; a further modification in Simplex regulators of later design than Model BB is that the calibration weights are not all internally carried on the dashpot pistons but may be mounted externally as shown at W. The regulator as shown employs both series S and shunt V solenoids, but it differs from the forms of the preceding sections in that these solenoids act *independently;* that is, the regulation before the battery obtains a predetermined voltage is *all* current regulation; and then when the voltage is sufficiently high to lift the plunger core the regulation is changed to constant-voltage type. When the voltage is below the predetermined point —about 39 volts on a 16 lead-cell equipment—the voltage coil core is down on its stops and its lever finger acts as a fixed abutment for the carbon pile, the variable position and pressure-changing member being then the finger of the current-coil lever; hence current regulation. However, when the core of the voltage coil lifts, this suddenly reduces the current and the lifting effect of the current coil being no longer great enough to hold the plunger core up, it therefore settles, and its lever finger becomes the fixed abutment of the carbon pile, while the voltage-coil lever finger is then the moving one and hence the regulation is of the voltage type. The characteristic voltage and current curves as produced by this regulator are shown in Fig. 34. It takes about 39 volts to lift the voltage coil into active functioning position, but less than 39 volts will hold it, hence the voltage of

the generator shows a slight drop and the current a more marked drop, when the voltage coil takes over the regulation, after which the current tapers off with time as in a straight constant-potential system. The connections of the regulator are shown in Fig. 35.

The automatic switch shown in the middle of the machine regulator panel at *A.S.* in Fig. 35 is of the standard "voltage-pull-in" coil type; it also has the regular series coil to increase the holding effect when the battery is charging, and to open up the circuit when the train speed falls low enough for the battery to discharge back into the generator. A double contact *XY* at the

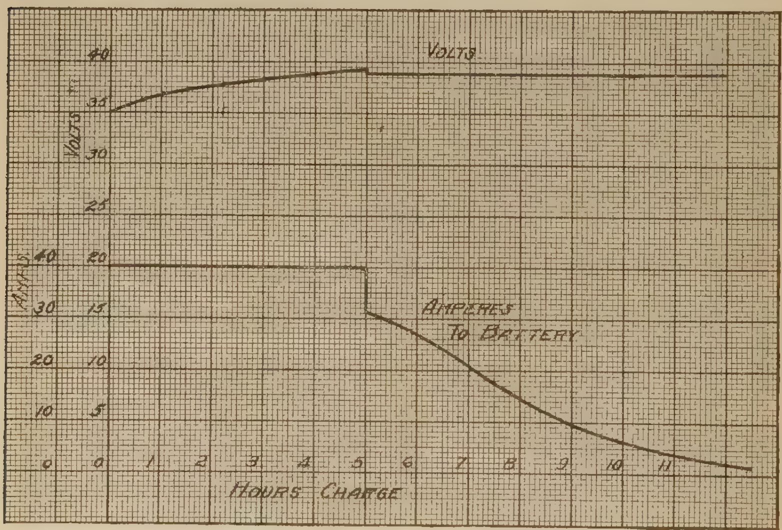


Fig. 34. Charging Characteristics of Gould Simplex Battery

top serves to short-circuit the series coil of the regulator when the generator voltage is low and battery is discharging so that the battery current to the lamps does not have to overcome the resistance of the current coil. The lamp current being thus shunted around the current coil of the generator regulator, its core drops to the stop, and a maximum pressure is put upon the field-circuit carbon pile, reducing its resistance to a minimum. This hastens the building up of generator voltage as the machine accelerates.

Another means to facilitate rapid building-up of voltage is introduced by the small resistance unit between the minus termi-

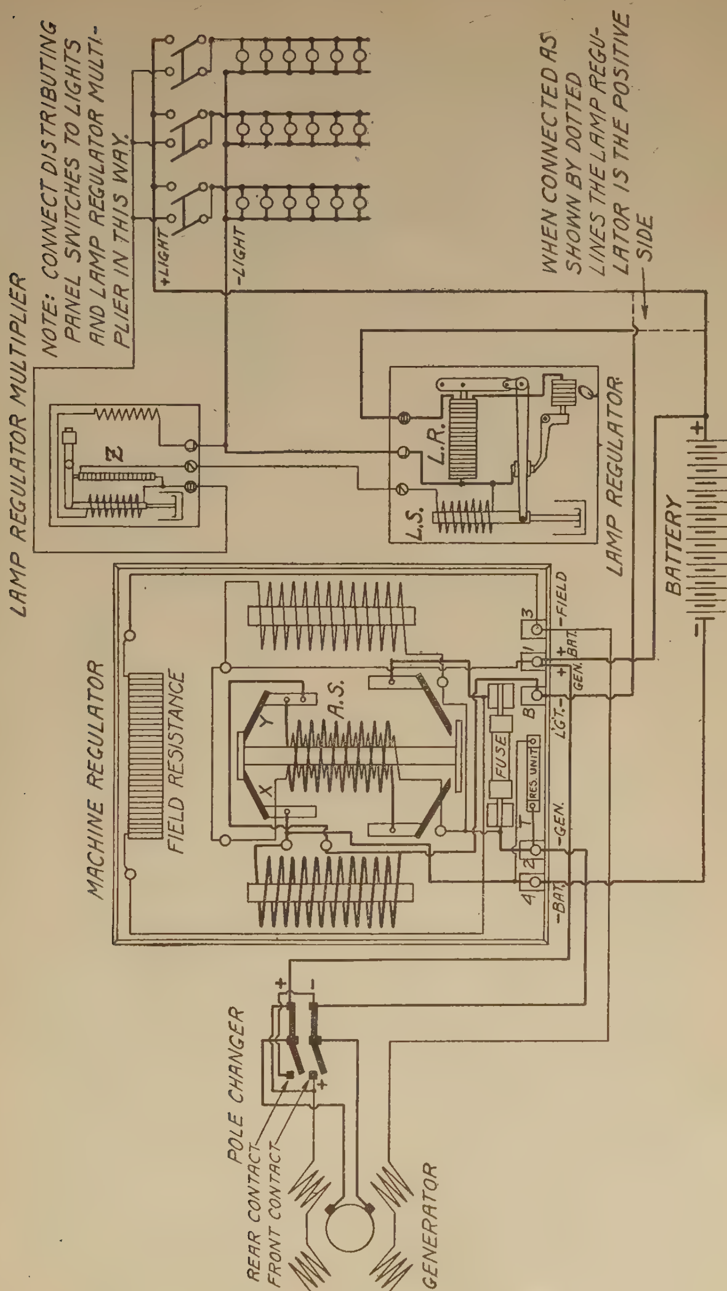


Fig. 35. Connections of Gould Simplex, Type BB, Regulator

nals of the battery and generator, bridging the automatic switch. This allows a small tickler current to flow, thus preventing loss of residual magnetism and it also aids in breaking down contact resistance between brushes and commutator. This small resistance unit is shown at *T* in Fig 35.

Lamp Regulator. The lamp regulator comprises two active parts, the main regulator and the auxiliary regulator or multiplier, as shown in Fig. 35. The main regulator has a carbon-pile resistance *L.R.* in the negative line of the lamp circuit; the pressure upon it is varied in inverse proportion to the lamp voltage by means of the shunt-connected solenoid *L.S.*, and hence its resistance is increased as the lamp voltage tends to rise. This shunt coil has in series with it the small carbon pile *Z* of the regulator multiplier, the resistance of which varies inversely as the lamp voltage; hence the effect of voltage change on the main resistance *L.R.* is magnified and the resulting regulation of lamp voltage is excellent. If the battery voltage falls very low, it is desirable to cut out the resistance of the main carbon pile *L.R.* and this is accomplished by the contacting of the lamp regulator lever with the lower carbon low-resistance group, *Q*, which will then shunt *L.R.*

Regulator Adjustments. The value of the current which it is desired to have the current coil regulate, is adjusted by means of the weights applied to the plunger core of the current coil. These weights may be riveted to the dashpot position as in Type BB, or for fine adjustment they may be mounted on the top of the plunger, as in Type BB-9, and other later types.

The voltage coil of the regulator is adjusted to its stop-charge voltage in the same manner as the current coil, and the lifting voltage is, on 30-volt equipments, usually set at 39–40 volts; with higher voltages it would vary in proportion. When setting up a regulator for adjustment with no current passing through either coil, a cold field-resistance pile, for proper positioning, should have such length that if the voltage-coil core is on its stop (that is, with the rollers at the top of the core), the current-coil core should be lifted about $\frac{1}{16}$ inch to $\frac{1}{8}$ inch and conversely, if the current-coil core is down, the voltage-coil core should be similarly lifted.

Automatic Switch Adjustment. The automatic switch is adjusted to close at a generator potential of 32 volts on 30-volt systems, and at 62 volts on 60-volt systems. If the adjustment is not correct, it may be adjusted by loosening the set screw at

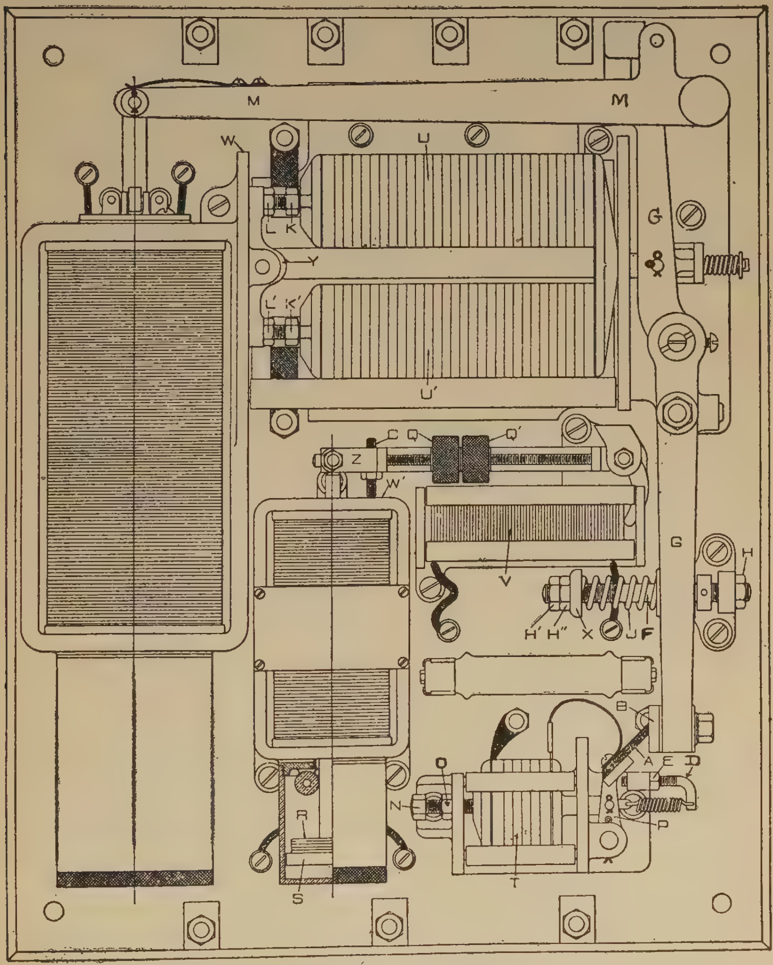


Fig. 36. Types M and M-2 Gould Lamp Regulators

the top and raising or lowering the solenoid core in order to decrease or increase, respectively, the "cut-in" voltage. The adjustment of the top and bottom contacts should be such that there is about $\frac{1}{64}$ inch follow-up on either incoming one before

the outgoing one opens. This ensures firm contacts on the one carrying the current.

Lamp Regulator Adjustment. This regulator, as has already been shown, has many parts, hence considerable care must be taken in setting it up. To adjust it, proceed as follows: Block the main lever *M*, Fig. 36, so that it rests about one inch above the stop *W*. Adjust stud *F* so that lever *G* is in a vertical position; then adjust stud *D* so that top of brush *A* clears contact button *B* by $\frac{1}{16}$ inch; lock studs *D* and *F* by means of their lock nuts *E* and *H*, respectively. Set the screw *N* so that the carbon pile *T* has its plates in such loose contact that movement of lever *P* changing gap between *A* and *B* by $\frac{1}{64}$ inch will put the pile under full compression; lock *N* in position with lock nut *O*. The spring *J*, which acts on the main carbon piles *U* and U^1 should be compressed by means of nuts *H* and H^1 until distance of face of washer *X* from lever *G* is about $1\frac{3}{8}$ inches.

Remove blocking between *W* and *M* and allow *M* to drop until it rests on *W*; then by means of *K* and K^1 adjust to full pressure on carbon piles *U* and U^1 and *T* which is indicated by lever *M* rising off stud *W*. The pressure on piles *U* and U^1 should be made as nearly equal as possible. The condition is indicated by the balancing of the equalizing lever *Y*; finally, lock *K* and K^1 in position using lock nuts *L* and L^1.

Multiplier Adjustment. The stud *C* should be set so that the lever *Z* may come within $\frac{1}{2}$ inch of the frame W^1. The number of carbon discs in pile *V* must be sufficient to allow full compression through an upward movement of $\frac{3}{8}$ inch of lever *Z*, and at the same time allow full release when *Z* is in its lowest position. The lamp voltage is raised or lowered by sliding the balancing weights *Q* and Q^1 to the left or right, respectively. The range of motion of *Q* and Q^1 is effective for a two-voltage adjustment on 30-volt loads. A greater range may be secured by alteration of weights on the piston of the multiplier, as at *R*. The standard weights sent with the regulator will vary the regulator setting by one volt per weight added or removed.

Causes of Failure. Failure of the battery may be due to any one of the following causes:

1. If a battery charged by a Gould Simplex System shows

signs of overcharge such as softened positive plates or excessive evaporation, the trouble may be due to (a) sticking of the core of voltage coil of the regulator; (b) open circuit in the voltage coil connections; (c) over-weighting of the core. These defects tend to continuous constant-current charging.

2. If the battery shows signs of persistent undercharge, such as sulphated plates or low specific gravity, this may be due to (a) undersetting of voltage coil, stopping charge too soon; (b) high resistance in battery circuit connections.

3. Failure of battery to charge at all may be due to break in automatic-switch shunt coil, loose belt, open field circuit, or failure of pole-changing switch to function.

4. If regulators are sluggish in action this may be due to dirt or grit in the bearings; to too-close adjustments of openings in piston of dashpot; or to low viscosity of the oil in the dash-pots. In connection with this last *it is important to use* the dashpot liquid furnished by the Gould Coupler Company—called "Dasho"—as it maintains the same viscosity over wide temperature ranges.

AXLE-DRIVEN SYSTEM OF THE U. S. LIGHT AND HEAT CORPORATION

The U. S. Light and Heat Corporation has had various forms of axle-driven train-lighting outfits on the market, but in recent years it has adopted a modified constant-potential system in connection with ampere-hour meter control.

Generator. The generators are, as usual, shunt-wound, and they may be used for truck or body mounting. They are designed to operate on the standard 30-, 60-, and 80-volt systems, and are obtainable in 1, 3, and 4 kw. capacity. A typical link suspension employed by the U. S. Light and Heat Corporation is shown in Fig. 37. The generator is supported on a cradle composed of the horizontal cross rods, *BB*, and belt tension is adjusted by means of the springs *S*. The suspension is bolted to the truck by means of the longitudinal bars *AA*.

Pole Changer. As in all equipments, where the direction of rotation of a generator may be reversed, the dynamo employed in the U. S. Light and Heat Corporation system is provided with a

pole changer to maintain current flow in the proper direction to charge the connected batteries. The pole changer is of the rotating type; the brush-holders are mounted on a ball-bearing supported ring carrier. The ball bearing enables the ring to rotate freely with commutator drag. The angular range is limited by means of stops to substantially 95 degrees in the case of four-pole machines, the extra angle of $2\frac{1}{2}$ degrees on each side being found necessary for proper commutation.

Generator Regulator. The generator-regulator panel carries upon its face the automatic switch, the regulating solenoid-adjusting resistances, the Sangamo ampere-hour meter, the field

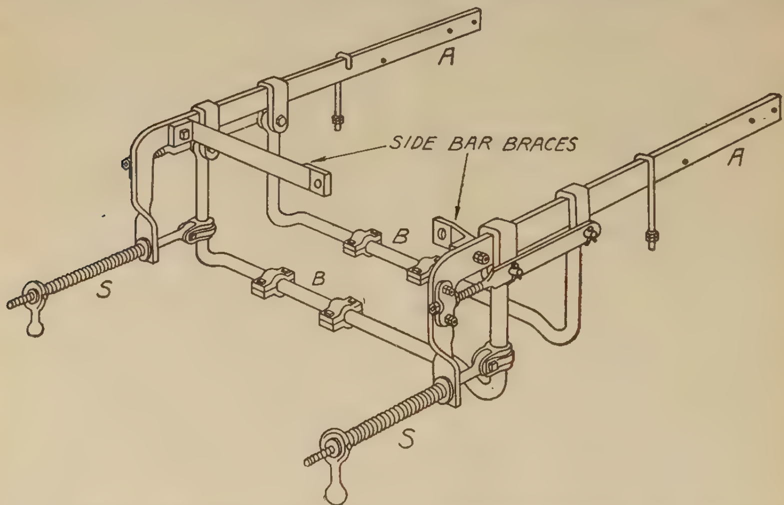


Fig. 37. Standard Wide Link Suspension Used by United States Light and Heat Corporation

rheostat, the lamp regulator, and protective fuses for armature and field circuits. The appearance of this panel is shown in Fig. 38. The diagram of connections is shown in Fig. 39. Examination of the regulator and its circuit connections shows that the regulator solenoid is provided with two windings, one in series with the battery load and one in shunt across the generator. The series coil, however, is not as powerful as the shunt coil, and hence the regulator may be called a modified constant-potential one. The function of the series winding is to provide a generator protection, should the battery be very much discharged. If charge by means of constant potential be attempted with a badly

depleted battery, the current may be for a short time of an excessive value, perhaps sufficient to injure the generator or to blow the armature-circuit fuses. However, as the regulator

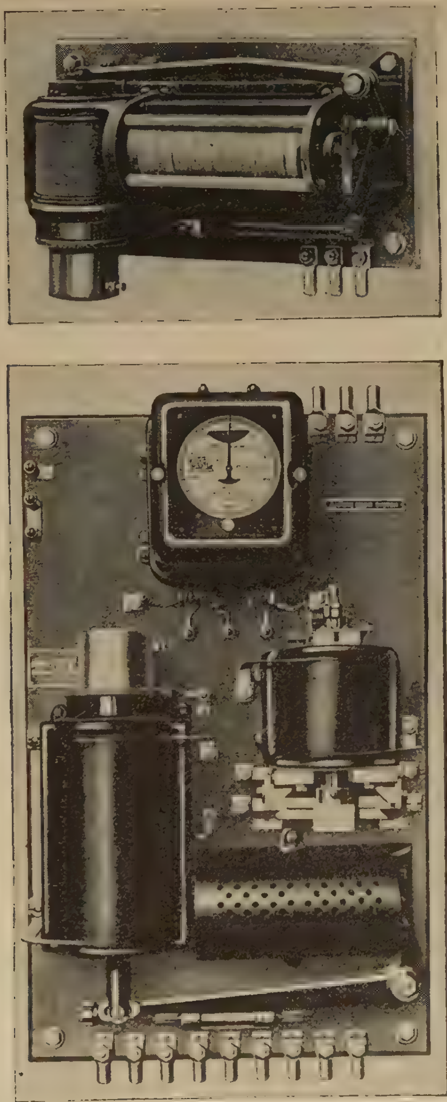


Fig. 38. Generator Regulator Panel and Lamp Regulator

Courtesy of United States Light and Heat Corporation, Niagara Falls, New York

solenoid is provided with a moderate number of turns in series with the battery, the ampere turns of the series coil, coacting with those of the shunt coil, will produce enough lifting effect to reduce this large current to a value less likely to do harm to the equipment. The voltage coil of the regulator, in running condition, coacting with the series coil, is so designed that the current taper on 30-volt systems and 250 ampere-hour batteries is from about 42 amperes to 20 amperes to produce substantially full charge in

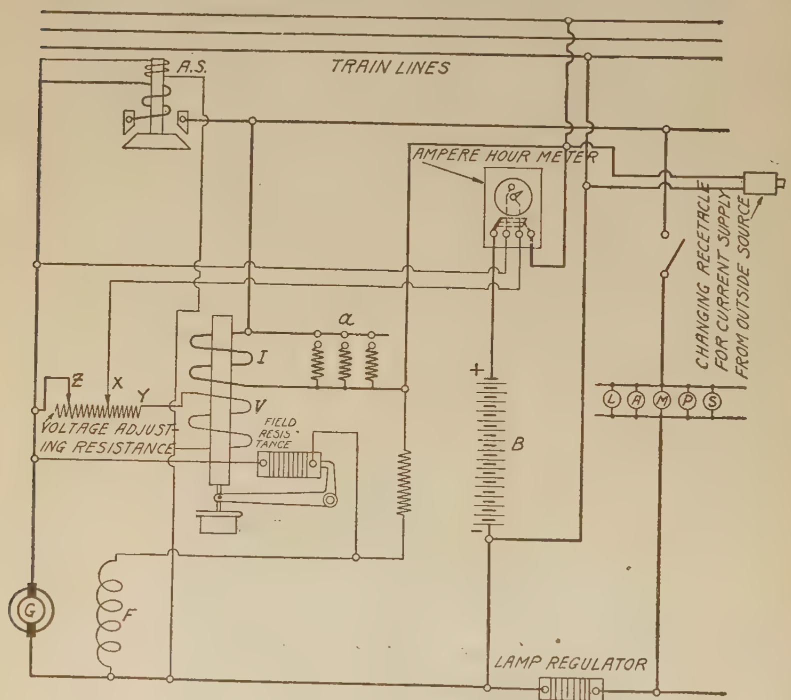


Fig. 39. Connections for Type C Regulator Equipment

7 or 8 hours. The continuance of such a charging current will ultimately produce a battery overcharge with its accompanying troubles. To obviate this a stop-charge device is introduced. In the earlier outfits of the U. S. Light and Heat Corporation, this stop-charge device was a battery-voltage-operated relay, which would function to cut out resistance in series with the voltage coil of the solenoid and make it stronger, so that the charge would be reduced by the lifting of the solenoid core and there

would be a consequent increase of resistance of the shunt field circuit of the generator. A second stop-charge method employed an ampere-hour meter which, after sufficient ampere hours of charge had been supplied to the battery, operated contacts controlling the relay. In the present standard form, Type C, the relay has been eliminated and the ampere-hour meter works directly to cut out resistance in series with the voltage coil of the regulator. The connections shown in Fig. 39 are for the latest form. The shunt *a* around the series coil of the regulator is for the purpose of altering the capacity of the equipment. To

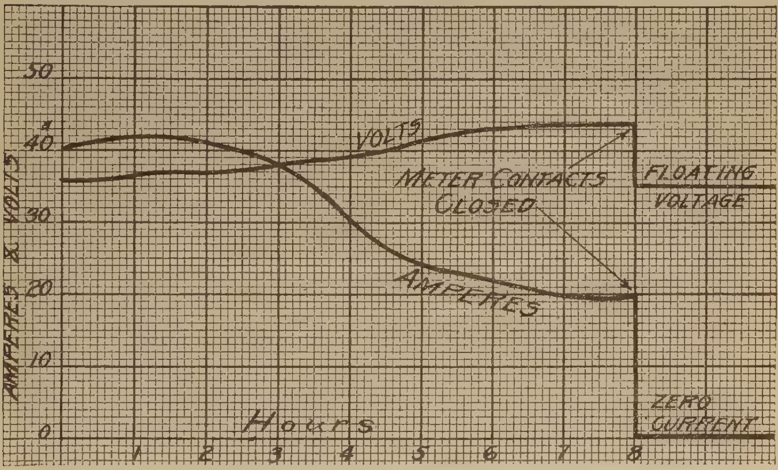


Fig. 40. Modified Constant-Potential Battery Current Regulation

increase the capacity, the steps across the shunt are increased in number. To reduce the capacity the number of steps is decreased. The small resistance in series with the voltage coil has two functions, namely: that between X and Y is made adjustable to obtain voltage regulation, and that between X and Z is cut out by the ampere-hour meter to reduce generator voltage to a battery-floating value. The charging characteristics of this regulator starting with a depleted battery are as shown in Fig. 40. The slight rise in voltage and current shown in the curves is caused by heating of the voltage coil of the regulating solenoid, temperature compensation not being quite complete.

Lamp Regulator. The lamp regulator consists of a standard carbon-disc type of resistance placed in series with the lamps, and a lamp-potential-operated solenoid which varies the pressure on the carbons inversely as the lamp voltage, so that at high voltage a larger resistance and hence larger *IR* drop obtains than at lower voltages. The adjustment of the regulator is either by change in spring tension or in positioning the plunger core.

Automatic Switch Adjustment. To adjust the automatic switch, open the generator fuse and push the plunger up and down to see that it works freely and to check up on the condition of the contact between the laminated copper brush and the contact blocks. The laminated contact brush should bend slightly to get a good wiping contact; if it does not, adjust the shims in the carrying stirrup until the bending upon closure obtains. The automatic switch is adjusted to close at 30 volts; if it does not, a proper adjustment may be made by turning up or down the castellated nut on the tail rod at the top of the switch.

Adjustment of Generator Regulator. Before operating the regulator examine it carefully to see that it is clean and that the plunger and lever mechanism work freely. If the dashpot vent is opened wide the lever mechanism when moved up and down by hand should bounce upon the carbon pile when suddenly released. The next thing to do is to see that all the circuits are closed and that no lamps are burning. Then as the train accelerates, the automatic switch should come in at 30 volts; if not, it may be adjusted as already described. Turn the hand of the ampere-hour meter, by means of the meter key, to about 25 or 50 ampere-hours' discharge condition to make certain that the meter contacts are open. Raise the lever of the generator regulator until the disc of the ampere-hour meter comes to a dead stop and then open the battery circuit, either by means of the battery switch or by disconnecting the positive wire of the battery at the bottom of the panel. Lower the lever slowly and note the voltage of the generator; remove the hand from the lever and move the right-hand sliding contact on the resistance unit on the top of the panel to its extreme right-hand position. The voltage will then come to about 50. Move the slider to the left until the voltage is reduced to 45; this is the open battery-

circuit voltage adjustment and the slider should be set up in that place. Next, turn the hand of the ampere-hour meter to zero to close the contacts and observe the voltage. If this is not 35 volts, adjust the left-hand slider until such voltage obtains. This is the floating battery voltage. Turn the hand of the ampere-hour meter back again to indicate a discharged condition and observe that the voltage again rises to 45. Close the battery circuit and note that the voltage drops to some value between 35 and 45 and that the battery is charging. After this has been done, no further adjustment need be made, except to set the hand of the ampere-hour meter at the true state of battery discharge. The safest way to set the ampere-hour meter is to give the battery a gassing charge and then turn the ampere-hour meter contact to full charged position. The series coil of the ampere-hour meter should also be adjusted. This is accomplished by increasing or decreasing the number of shunts connected in at *a* in the wiring diagram, Fig. 39. The best way to do this is with a discharged battery; and to decide upon the maximum charging current to be allowed, which, in a 250 ampere-hour battery, would be substantially 40 amperes, adjust the shunt by increasing or decreasing the number until about 42 amperes is indicated as flowing to the battery. Naturally for this adjustment an indicating ammeter is necessary, and this could be placed in circuit between the positive battery lug at the bottom of the panel and the positive battery lead. In this regulator, as in all others provided with battery stop-charge devices, the stop-charge voltage-coil control is connected on the generator side of the automatic switch, so that opening the automatic switch will cause a full charge rate to obtain for such time as the voltage of the system may require it.

Adjustment of Lamp Regulator. In order to adjust the lamp regulator open the dashpot vent; move the lever up and down to see that the mechanism is free. Examine the carbon-pile resistance to see that the carbons are in perfect shape; thoroughly clean them. There should be 32 standard discs. The conical compression spring should be tested for strength and should compress at about 10 pounds, a departure of plus or minus two pounds is the limit; if this is exceeded, a new spring should be obtained. The pistons and dashpots should be tested as follows:

Set the dashpot on a level surface and place the piston itself in the dashpot; close the dashpot tight and note how long it takes for the piston to travel its full distance in the dashpot. This should be from 50 to 60 seconds. Replace the piston and the dashpot in their working positions. Adjust the screw and the vertical member of the bell crank lever until its long arm just begins to move downward. Turn on the smallest lamp load and adjust the tension spring nut until the potential at the lamps is 31 volts. The final spring adjustment, however, should not be made until the regulator and the carbons are fairly warm. This condition will obtain after about one half hour's operation at full load. Check the adjustments at different lamp loads and use that spring setting which gives the best average lamp voltage approximating 31 volts.

Indications of Trouble. 1. Should the battery show signs of overcharge, such as softening of the positive plates, excessive gassing or excessive evaporation, it indicates that the stop-charge mechanism is not functioning. This may be caused by (a) contacts of the ampere-hour meter being broken; (b) leads to the ampere-hour meter being broken, or sticking of the regulator; (c) the shunt coil being broken, in which case the rate of charge is so high as to blow the main fuses.

2. Should the battery show signs of undercharge, such as low specific gravity or sulphated plates, it would indicate too strong a voltage coil. This may be occasioned by (a) improper setting of the adjusting resistance; (b) short-circuit between Z and X, or X and Y of the adjusting resistance in the wiring diagram, Fig. 39; (c) frozen contacts in the ampere-hour meter; or (d) high resistance contacts in battery circuit which may cause sufficiently high voltage to reduce charge rate.

3. Failure of the ampere-hour meter to show any charge going to the battery (assuming the ampere-hour meter to be in proper condition), may be due to (a) failure of dynamo to generate as caused by open field fuse or break in field circuit; (b) poor brush contact on the commutator; (c) automatic switch being broken in shunt-coil winding or contacts being burnt; (d) armature circuit fuse being open; (d) belt slipping or being broken.

4. To test if the generator is operating satisfactorily, a voltmeter may be placed across the generator leads and the voltage noted. If this is correct the trouble is either in the generator main fuse or in the automatic switch. The generator may be motored to determine if it is all right in all its parts. Slacken belt tension by loosening up on the tension springs; slip off the belt and turn the armature by hand several revolutions in one direction; apply full pressure to the field rheostat; remove armature fuse; block automatic switch in closed position; and replace armature fuse. Remove blocking of automatic switch. If the switch is O.K. it will hold itself closed. If the generator is O.K. it will rotate very slowly as a motor; the motion may be accelerated by gradually raising the regulator core. To determine if the generator will motor in the opposite direction satisfactorily, increase the compression on the carbon pile to its maximum and then pull the armature fuse. Rotate the generator armature by hand several turns in the reverse direction so as to rock the brushes over; then proceed as before with the regulator. If the motor is in proper condition for this direction of rotation it will revolve slowly at first and finally accelerate as the core of the regulator is raised. If the armature rotates properly in both directions with these tests, it shows that the generator brush rigging and field circuits are operative and properly connected.

In all these tests it is naturally assumed that the battery has been properly connected as regards its polarity; this may be checked by placing a voltmeter across the automatic switch when the same is open. If the voltmeter indicates substantially zero volts, then the battery is properly connected. If it indicates substantially twice battery voltage with the train under way, then the battery connections are reversed. If the generator closes its automatic switch with battery reversed, the armature fuses will probably be blown, because this would constitute a double voltage short. The positive battery terminal must always be connected to the plus battery terminal of the switchboard or to the plus generator terminal of the switchboard, depending upon the particular marking employed.

5. If regulators are sluggish or hunting, this is due to improper setting of dashpot vents.

STONE-FRANKLIN CAR-LIGHTING EQUIPMENT

The Stone-Franklin System, known in England as the Stone System, after its inventor, is one of the first successful train-lighting equipments developed, and is unique in comparison with those considered in the preceding chapters, in the method of generator and lamp-voltage regulation employed.

Generator. The axle-driven generators are shunt-wound, 40-volt machines, of 1.6 kw. and 3 kw. respectively. They are

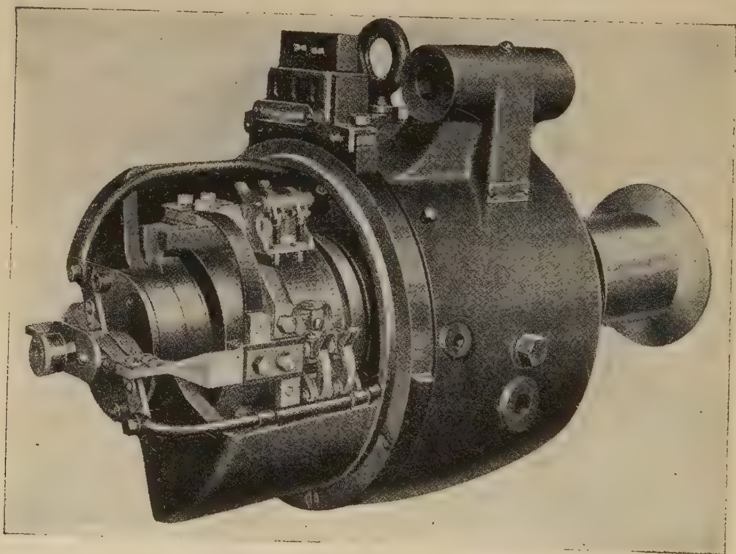


Fig. 41. Stone-Franklin Generator with Dust Cover Removed
Courtesy of Franklin Railway Supply Company, New York

provided with ball bearings and flanged pulleys. Their general appearance is as shown in Fig. 41.

Suspension. The generator suspension, Fig. 42, is substantially a body-hung type. This suspension in connection with the belt constitutes the generator regulator. The output of the generator depends upon the amount of belt tension adjusted by the handwheels *I* and *R;* the former is used to increase and the latter to decrease the tension, and hence the output. The generator is provided with a tension indicator which is mounted upon the machine housing at the commutator end, as at *B*. This indicator comprises a curved tube having an indicator ball within it. The

tube is provided with index marks to show the inclination of the generator to the right or left of a vertical line through its shaft. For full output the handwheels *I* and *R* are rotated on their spindles until the steel ball assumes its position under the "full indication." The belting must not be of rubber, as this does not slip freely enough, but should be of heavy canvas or its equivalent; that recommended by the Stone-Franklin Company is known in the field as "Frysco" belting.

Generator Regulator. The generator regulator action is as follows: Suppose the train to have passed the critical speed at which the automatic switch closes and upon which the battery will begin to charge. However, as the car accelerates, the generator load will increase until the driving effort exercises more than

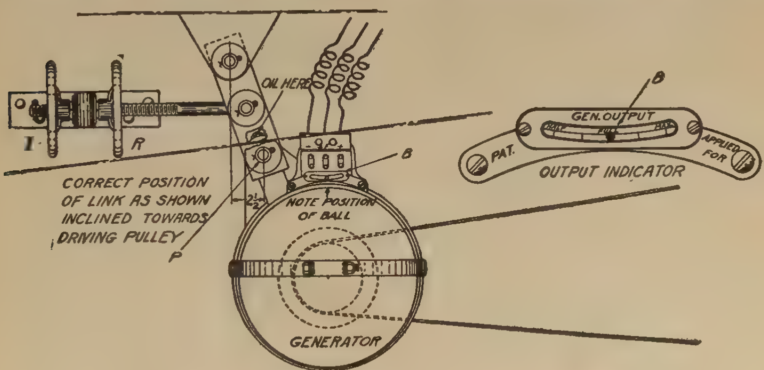


Fig. 42. Suspension and Regulation Devices of Stone-Franklin System

full-load belt tension. This draws the generator closer to the truck and reduces the belt tension, allowing it to slip, thus keeping the generator output substantially constant. Should the train slow down, the belt-pull momentarily decreases; the generator, however, owing to its suspension, will tend to swing away from the truck, increasing the belt tension and bringing the generator output up again. Thus, if the battery is receiving a charge, the flow of current to the battery for short intervals would be substantially constant; but as the battery approaches full charge with a corresponding increase of voltage, the current will gradually be decreased, owing to the fact that the generator can only carry a constant load. Similarly, if a lamp load is turned on, the generator will furnish current to the lamps through ballasting resistances,

and the battery rate of charge will also diminish, though the total load on the generator will remain substantially constant.

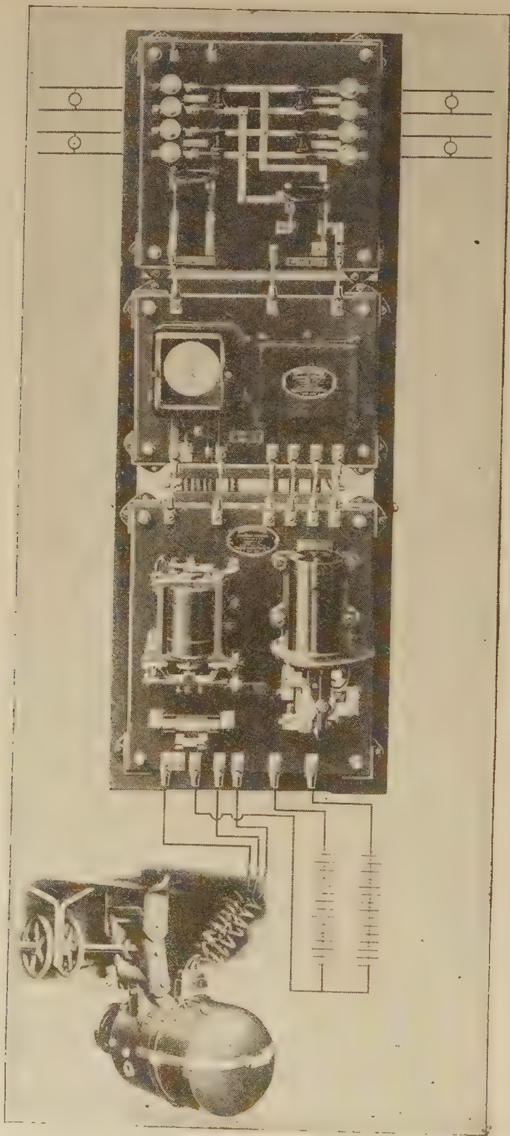


Fig. 43. Arrangement of Stone-Franklin Car-Lighting System for Passenger Car Lighting

Panel Arrangement for Passenger Coach. The Stone-Franklin Company for standard passenger coaches employs what is known as its Type D panel, Fig. 43. This equipment is used in connection with two sets of batteries, one of which is connected to the generator and receiving charge while the train is under way; the other, if lamps are burning, has the lamps connected across its terminals, though this lighting battery floats on the generator line. If no lamps are burning with the main lighting switch open, both batteries are charged in parallel. The generator and panel arrangement for a passenger coach is shown in Fig. 43, and the

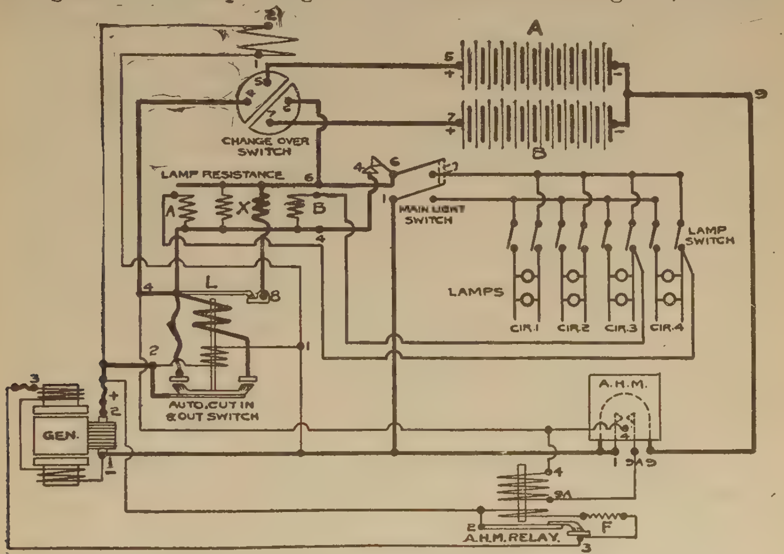


Fig. 44. Connections of Stone-Franklin Type D Equipment

simplified wiring diagram is shown in Fig. 44. The operation of the system will be described by considering the latter diagram.

Examination of this diagram shows an automatic switch of the usual type with series and shunt windings. At the top of the automatic switch is a short-circuiting lever arm L which, when the generator is operating below cutting speed, falls and short-circuits the resistance X which is located between the generator circuit and the battery to which the lamps are connected. The short-circuiting of this resistance X places the second battery in parallel with the first, both carrying the lamp load when the train is standing idle or operating at a low speed.

As the train accelerates, the automatic switch comes in, the lever arm *L* is lifted by the plunger core of the automatic switch and inserts the resistance *X* in series between the generator and the battery *B*, which becomes a floating battery and fixes the lamp voltage. The battery *A* will be connected directly across the generator through the contacts of the automatic switch, through the series coil of the automatic switch through lead *4*, through change-over switch to lead *5*, lead *9*, ampere-hour meter, and lead *1*. The ampere-hour meter is arranged to operate a relay which, upon closure of the contacts of the ampere-hour meter at full bat-

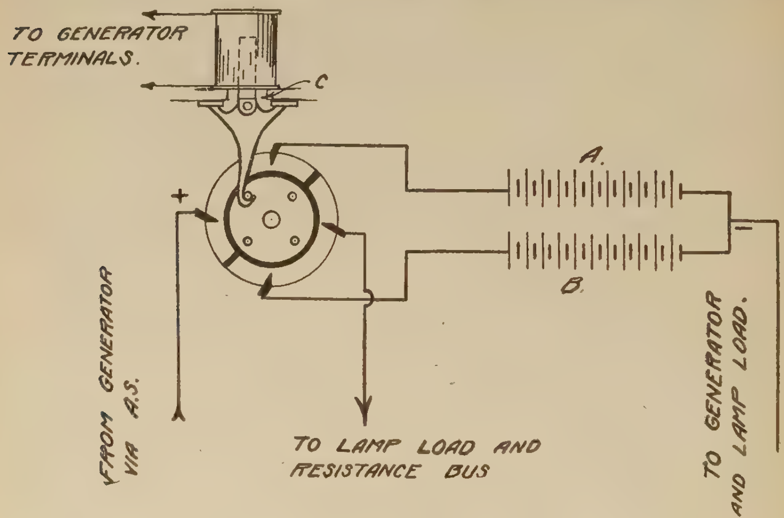


Fig. 45. Change-Over Battery Switch

tery charge, inserts a resistance in the generator field and makes it inactive.

The change-over switch employed on the Type D panel or double-battery outfit alternates the batteries *A* and *B* with reference to their electrical position in the system every time the train starts, and in this manner a substantially charged battery is always connected across the lamps. The operation of the change-over switch is as follows: This switch is provided with a shunt winding across the generator terminals on the generator side of the automatic switch, Fig. 45. Thus every time the generator voltage falls on stoppage of the train, the core *C* of the change-over

switch will drop, clearing the stud below, as its pivoted support will allow the hook to swing off. However, as the train accelerates and the cut-in voltage is reached, the core of this switch is raised; the hook at its extremity engages with the lower stud of the pole-changing disc and raises it one-fourth of a turn. This will shift the connections from the battery, which has been undergoing charge, to that which has been acting as the lamp-floating battery.

Lamp-Voltage Regulation. The lamp-voltage regulation, while the train is in motion, is obtained by the divided batteries, The lamp current is furnished by the generator when the train is operating, the current passing through suitable lamp resistances which are placed at the top of the frame of the Type D panel, Figs. 44 and 45. These resistances are adjusted by the manufacturer to insure the current being supplied by the generator. The resistance tubes are held between the two bus bars, the lower one being connected to the high voltage lead *4* while the upper bus is connected to the 30-volt side, or the plus terminal of the floating battery. There is no regulation of lamp voltage to a substantially constant value; thus when the train is making a long stop and the battery is discharging, the lamps would gradually burn dimmer and dimmer.

Pole-Changing Switch. Like all battery-charging generators of the shunt-wound character the polarity of the generator terminals must be corrected for change in direction of rotation. The means employed in this machine are similar to those used by the Safety Car Heating and Lighting Company, and by the U. S. Light and Heat Corporation, namely, a ball-bearing supported brush rocker ring, which is dragged around by friction between brushes and commutator to the position necessary for the existing direction of rotation.

Indications of Trouble. 1. Should the ampere-hour meter show heavy battery discharge after a run, look for faulty belt tension, and increase the same if the indicator is reading below "full."

2. If the belt tension is found to be correct, inspect the armature circuit and field fuses.

3. If these are found to be correct, test out automatic switch and see that it makes proper contact and closes at about 34 volts.

4. The generator may fail to charge the batteries because of frozen contacts of the ampere-hour meter, which would keep the resistance F in Fig. 44 in series with the generator field circuit and thereby cut down the generator output.

5. Should the ampere-hour meter show full battery charge and lamp voltage be found low, examine the resistance short-circuiting brush L and see that its contacts are clean; if this is O.K., the trouble may be in the resistance units, some of which might be open-circuited.

6. The shunt winding of the change-over switch may be open-circuited so that the batteries are not shifted from charge to floating value after various train stops. In this manner the floating battery would always be in a discharged condition and when the train is running the lamps burning therefrom would be dim. If this condition obtains, one battery would show signs of overcharge and the other would have low specific gravity and signs of undercharge.

7. If both batteries show signs of overcharge (high specific gravity and considerable evaporation), this is caused by broken contacts in the ampere-hour meter or by open coil of the ampere-hour relay, which would prevent the operation of the stop-charge device.

8. Low voltage of the lamps may also be caused by poor contacts in the battery circuit, poor contacts in the change-over switch, excessive circuit or short-circuit in some of the cells, or by poor contacts on main lamp switch.

9. The generator circuits may be tested by motoring the generator. This may be done after slacking up the tension and removing the belt by closing the automatic switch. If the generator rotates properly in this direction, rotate the armature in the reverse direction several turns by hand and then close the automatic switch again. If the machine rotates properly in this direction as well, it may be assumed that the generator is operating satisfactorily. In making this test be sure that the ampere-hour meter hand is away from zero and that the relay contact at *3* in the figure is down so that the resistance F is short-circuited. *Never withdraw field fuse while motoring generator.*

Test on Battery Change-Over Switch. Remove the generator main fuse and alternately open and close the automatic switch, the

disc of the change-over switch makes one-fourth of a revolution every time the automatic switch is closed, if operating properly.

Ampere-Hour Meter Adjustment. If the ampere-hour meter reads zero and the lamp voltage is below its proper value, or the specific gravity of electrolyte of the battery is below full-charge value, this indicates that the battery and the ampere-hour meter are out of step. The meter and battery may be brought back

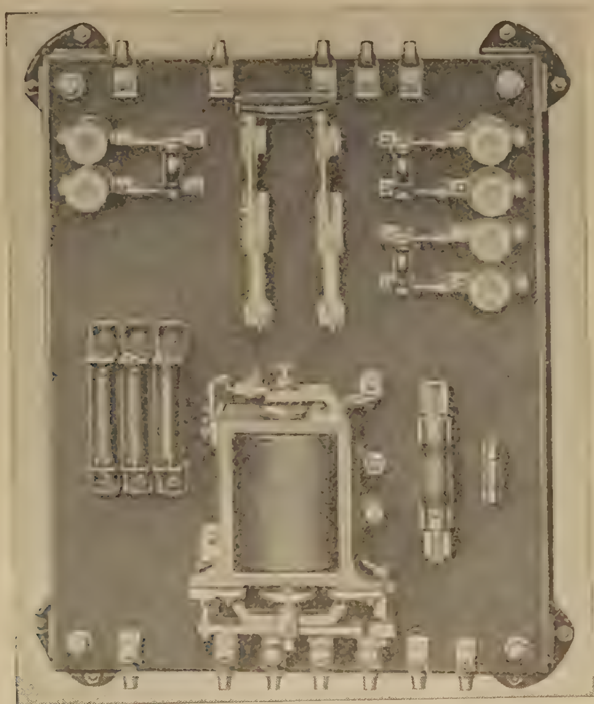


Fig. 46. Stone-Franklin Baggage Car Panel, Type S

into step by setting hand of ampere-hour meter back 25 per cent of the dial. Repeat the procedure until the lamp voltage is at normal value when the ampere-hour meter is at zero, the specific gravity of the electrolyte is up to full charge, and the cells are gassing.

The Stone-Franklin Company also makes up a simple baggage car lighting outfit. This comprises the small size of generator and a simple switchboard panel as shown in Fig. 46. No real lamp

regulation, however, is attempted here. Resistance is placed in the lamp circuits, when the battery is charging, to protect them from the high voltage, and it is removed when this condition does not obtain. The contact at the top of the automatic switch is opened on charge and cuts the resistance tubes into circuit; and when the automatic switch opens the top contact closes, short-circuiting the tubes. Naturally on long stops the lamp brilliancy of both systems will diminish as the battery discharges.

THE ELECTRIC STORAGE BATTERY COMPANY CONSTANT-VOLTAGE AXLE LIGHTING SYSTEM

The Electric Storage Battery Company Axle Lighting System differs from all the others discussed, in that it is a pure constant-

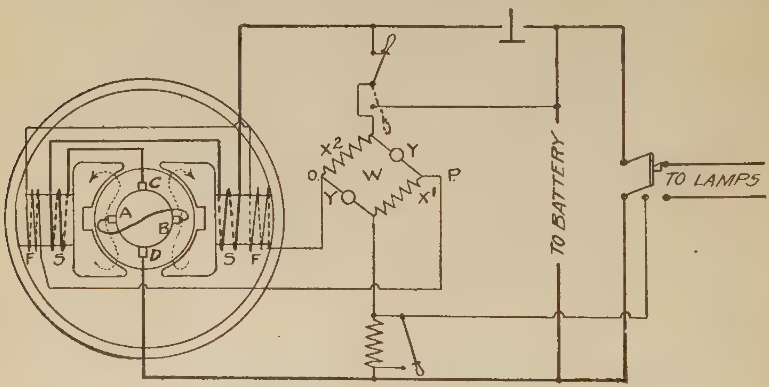


Fig. 47. Circuits of Rosenberg Constant-Potential Generator

potential system, and when the lamps are burning the voltage at the battery is the same as that at the lamps.

Generator. The generator is designed for a constant voltage of approximately 33½ volts with 15-cell equipments, and has a maximum current capacity at that voltage of about 80 amperes. The generator is built on what is known as the Rosenberg principle, that is, its main field is produced by a magnetomotive force developed by the armature winding. The general construction and circuit connections of the generator are shown in Fig. 47. The striking features of this machine are: (a) the large pole shoes slotted at their centers; (b) the small cores or necks; (c) the set of short-circuited brushes, as well as the brushes which are con-

nected to the load. These latter brushes, to distinguish them from the first set, are called the load brushes. The pole cores are provided with two windings. One winding S is in series with the load, the second winding F, termed the control winding, is connected across two points of a Wheatstone bridge, which in turn is connected at its other points across the generator terminals outside of the series field. This latter field winding F provides the primary field excitation controlling the voltage of the generator. The flux path of this winding is the same as in any direct-current machine from one pole through the armature core, through the opposite pole and back via the yoke to the starting point. Under normal operating conditions this magnetic field is comparatively weak and produces only a low-voltage difference between the short-circuited brushes, A and B. This low voltage, however, produces sufficient armature current to develop a considerable magnetizing force. This magnetomotive force produces a field at right angles to that set up by the field windings. It passes through the armature and the pole shoes, as shown by the arrows. This secondary flux produces the desired voltage across the load brushes C and D.


Fig. 48. Iron Wire Ballast

The Rosenberg generator requires no pole-changing device, because its polarity is independent of direction of rotation. This is owing to the fact that the voltage generated across the short-circuited brushes by the primary field is reversed, and the armature current flowing between the brushes A and B is therefore reversed in direction and thus the voltage across the brushes C and D is maintained correct. The regulation toward constancy of potential is due to the winding, F, connected, as already explained, to two points of the Wheatstone bridge. The bridge has two of its opposite arms composed of fixed resistances, X^1 and X^2, and two of iron wire filaments enclosed in glass bulbs filled with hydrogen. These are called ballast units and are made up as shown in Fig. 48, four of such units in parallel being employed in each of the arms YY of the Wheatstone bridge. Iron wire, when operat-

ing at a dull-red heat, has a very large temperature coefficient, and its resistance will vary considerably with small changes in the heating current. The design of the bridge for the standard 15-cell equipment is such that when the generator voltage is $33\frac{1}{2}$ volts the resistances of the arms X and Y are substantially equal. No current will flow through the field winding F, Fig. 47, under this condition, because the points O and P are of the same potential. If the voltage is lower than $33\frac{1}{2}$ volts, the resistance of the arms Y is less than that of the arms X, consequently they will carry more current, and this excess will flow through the field winding F from P to O strengthening the field winding and bringing up the voltage. As the voltage of the machine increases, P

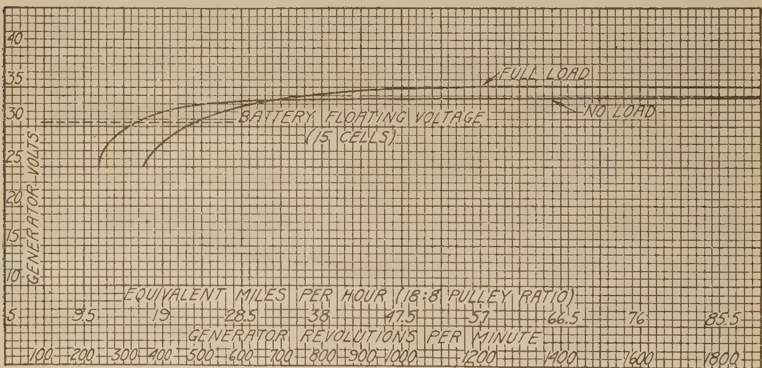


Fig. 49. Characteristic Volt Curves of Electric Storage Battery Generator

and O approach each other in potential and the field excitation becomes less and less; and when the voltage of the machine tends to exceed $33\frac{1}{2}$ volts, the resistance of the ballast units will be greater than that of the fixed resistances, and more current will flow through the arms XX of the bridge than through YY. This excess current flowing through the field winding F from O to P counteracts the residual magnetism and holds the voltage of the machine down and brings about its regulation to constant potential. Characteristic voltage curves of this machine are given in Fig. 49. The function of the series winding is to protect the machine against overload.

Generator Suspension. The Electric Storage Battery Company provides both body and truck suspensions. The former sus-

pension, Fig. 50, is substantially of the link type with standard belt tension spring. The body-hung machine is suspended by two supporting lugs, cast on the generator frame. These lugs are bushed, and a steel bar is passed through them, and this bar is in turn carried by the underframing of the coach. The belt tension is provided with a stud and spring. The general arrangement is shown in Fig. 51.

Regulator Panel. The generator control panel is shown in Fig. 52. Upon it are mounted the automatic switch and the arms of the Wheatstone bridge. The eight ballast resistances are at the top of the board, and their corresponding fixed resistance units are

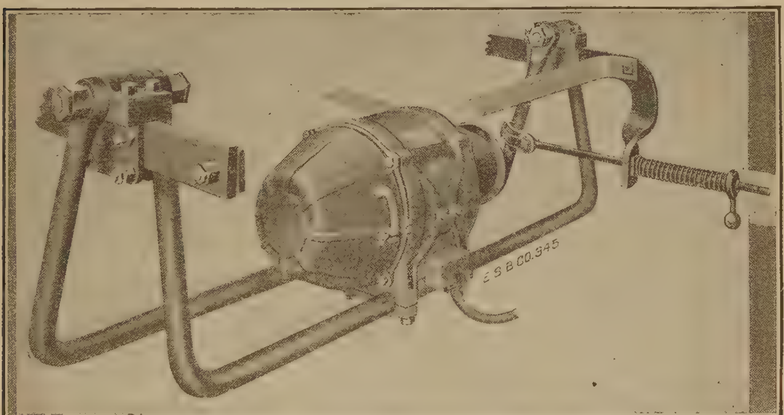


Fig. 50. Link Truck Suspension
Courtesy of The Electric Storage Battery Company, Philadelphia, Pennsylvania

at the right- and left-hand sides of the board respectively. In addition to this, there is mounted upon the board a resistance unit which is in series with the shunt coil of the automatic switch, and one in series with the Wheatstone bridge. The positive terminal of the Wheatstone bridge may be disconnected from the generator and connected to the battery positive side by means of a double-throw switch. The normal position of the switch is naturally the former connection; the second position is one for testing purposes, as it will permit the sending of a current through the bridge from the battery when the coach is not under way. This current in a few seconds heats the ballasts and fixed resistances. By feeling these it can readily be determined if they

are in operative condition. This connection will also send a considerable current through the control field winding and ensure a stronger residual field. The diagram of connections, Fig. 53, illustrates this connection, the switch being normally in the dotted position. The automatic switch is of the solenoid type and is provided with three windings, namely, the normal shunt coil S, the pull-in coil P, and a series winding R. The shunt coil at normal voltage is not of sufficient strength to close the automatic switch. It requires the assistance of the pull-in coil. This coil is connected by means of the auxiliary switch shown at the top of the automatic switch, between the generator and the battery positive terminals. The magnetizing coil of the auxiliary switch is in

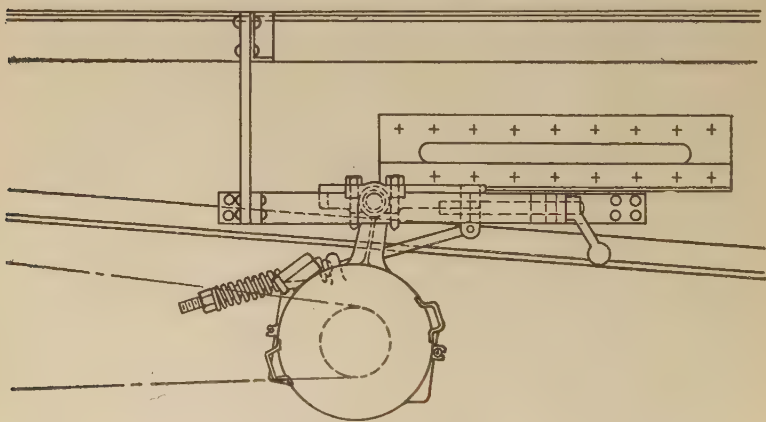


Fig. 51. Body Suspension of Electric Storage Battery Company Generator

series with the shunt coil S. When the generator potential exceeds 20 volts the current flowing through the shunt coil and the auxiliary coil is sufficient to close the contact and put the pull-in coil in circuit. As long as the battery voltage is higher than that of the generator voltage, the magnetizing force of the pull-in coil P opposes that of the shunt coil and the automatic switch will not close. However, when the voltage of the dynamo exceeds that of the battery by substantially one volt, the current in the pull-in coil produces a magnetizing force coacting with that of the shunt coil; the resulting lifting effect is sufficient to close the automatic switch thus connecting the generator and battery. The closing of this automatic switch is therefore determined by the

battery voltage, and will allow the connecting in of the generator for charging purposes at a lower speed when the battery is depleted. The generator is disconnected from the battery by means of the automatic switch whenever the generator potential falls below that of the battery.

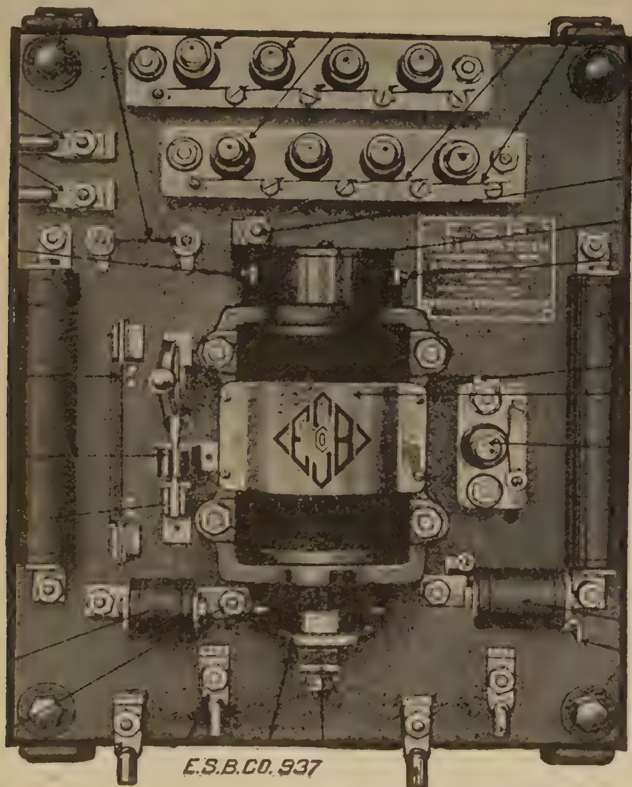


Fig. 52. Regulator Panel
Courtesy of The Electric Storage Battery Company, Philadelphia, Pennsylvania

At the lower left-hand corner of the generator panel, Fig. 52, is located a fixed resistance which is in series with the shunt winding of the automatic switch. This resistance has a zero temperature coefficient and serves to limit the effects of temperature on the operation of the automatic switch. At the lower right-hand corner of the panel is a voltage-raising resistance unit which may be short-circuited by a rod placed directly below it. This resistance unit is in series with the Wheatstone bridge and i·

normally short-circuited by the switch and by an extra blade on the lamp switch. When the switch *H*, Fig. 53, and the lamp switch are both open, the resistance at *H* is no longer short-circuited. The drop in this resistance lowers the voltage applied across the Wheatstone bridge; and in order to restore the latter to its normal balance value, the voltage of the machine will be increased by an amount equal to the drop in the resistance at *H*. This arrangement permits the voltage of the machine to be increased during a daylight run when no lamps are burning, in order to give the battery a high rate of charge should this be

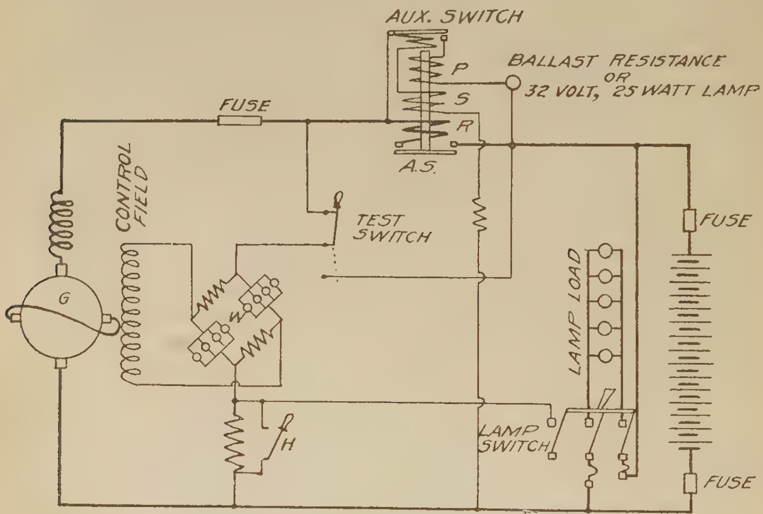


Fig. 53. Connections for Electric Storage Battery Company Axle System

necessary. However, when the lighting switch is closed, the resistance at *H* is immediately short-circuited, and the generator voltage is reduced to normal lighting value.

Since this system is a constant-potential charging one, no stop-charge device is necessary to protect the battery from overcharge. Means must be introduced, however, to raise the voltage of the generator should the battery be in a sulphated condition or should climatic temperature changes occur. This adjustment can be made by the resistance *R* if desired.

Indications of Trouble. 1. Should the battery show signs of overcharge, this is likely to be due to failure of the control field

winding F, Fig. 47, to function. For instance, should resistance arm X^1 be broken, the current will always flow through the field winding F from the point P to O, in which case constant-potential charge characteristic will be eliminated. This defect would be shown by lamp voltage rising and falling with speed. Similarly, should the generator fail to cut in excepting at very high speeds, failure of resistance X^2 would be indicated; or, conversely, the ballast $Y-Y$ resistances may be broken or out of adjustment.

2. Battery overcharge may also obtain if resistance R, Fig. 47, is broken. This difficulty would entirely destroy the action of the regulator field and cause battery overcharge when lamps are not burning. A rising and falling of lamp voltage, however, will not obtain when the lamp switch or the switch H is closed.

3. An open circuit in the connections of the field F, Fig. 47, would destroy the regulating properties of the machine as in the above case, excepting that the regulating properties would not be restored upon closure of the lamp switch. Whenever the above conditions obtain it is therefore advisable immediately to test out the bridge and the field winding F. This may be done by throwing the test switch on the control panel so that it will place the battery across the Wheatstone bridge, and reading the voltage across the points O and P. If the indication is 2 to 3 volts the field circuit is O.K., the positive terminal of the volt-meter being connected to P. An open field circuit would be indicated by a reading of 6 to 8 volts, and reversed readings of any value would indicate failure in some of the arms of the Wheatstone bridge. These may be checked by comparing the voltages across the similar arms, which naturally should be substantially the same.

4. Battery undercharge may also be due to the failure of the automatic switch to close, excepting at excessively high speeds. This difficulty may be occasioned by an open circuit in the shunt coil winding.

5. Battery undercharge may also be due to failure of generator to build up. This may be occasioned by brushes A and B, Fig. 47, not making contact or by an open circuit between them. Under this condition the generator will fail to maintain fixed polarity independently of direction of rotation.

6. Battery undercharge may be caused by high-resistance contacts in battery line or at battery terminals, or by the presence of sulphated plates. These defects reduce the rate of charge, and in a given run prevent proper charge.

7. Low voltage, and therefore battery undercharge, may result from short-circuiting of part of resistance *R*, Fig. 53.

8. Battery overcharge, yet low voltage at lamps, when car is idle, may be due to short-circuit in some of the cells, due to sediment or other foreign matter.

HEAD-END TRAIN-LIGHTING SYSTEMS

Head-end train-lighting systems are those in which only one generator unit obtains per train, instead of one per car. Each coach, however, has a storage-battery equipment which is charged from the generator unit while the train is under way, and which supplies current for the lights of the coach when the train is standing still or the individual car is cut off.

The term "head" was derived from the fact that the generator unit was located in the first car of the train—usually the baggage car—though it may be located anywhere in the train.

Equipment. The generator may be driven by any prime mover. In modern practice, however, the driving device is usually a high-speed steam turbine operating at 3600 or 4500 r.p.m. on 60 pounds steam pressure. The generator is usually designed for a 32-cell battery, giving therefore 80 volts and 25 amperes, that is, 20 kw. capacity. There is no essential difference between any of the turbo-generator equipments or in their circuit connections except that one system, *A*, uses one battery per coach, and the other, *B*, two sets of batteries in parallel per coach. The power distribution throughout the train is by a 3-wire train line—two negative leads and one positive. The lamps are generally connected between the outside negative and the common positive, while the batteries are connected between the middle negative and the common positive.

The connections of one of the standard A types of head-end lighting systems are shown in Fig. 54. It is to be noted that the switchboard equipment of this system is substantially that of any small isolated power plant furnishing current to charge

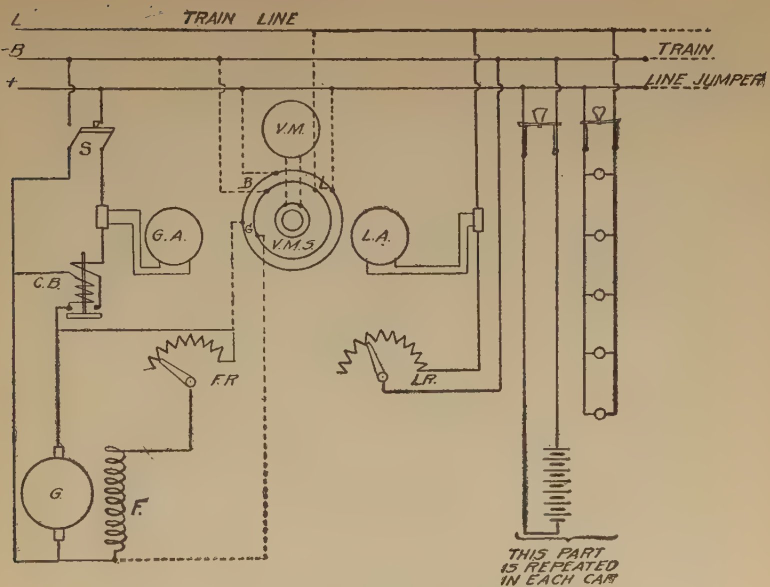


Fig. 54. Connections for Head-End Lighting System

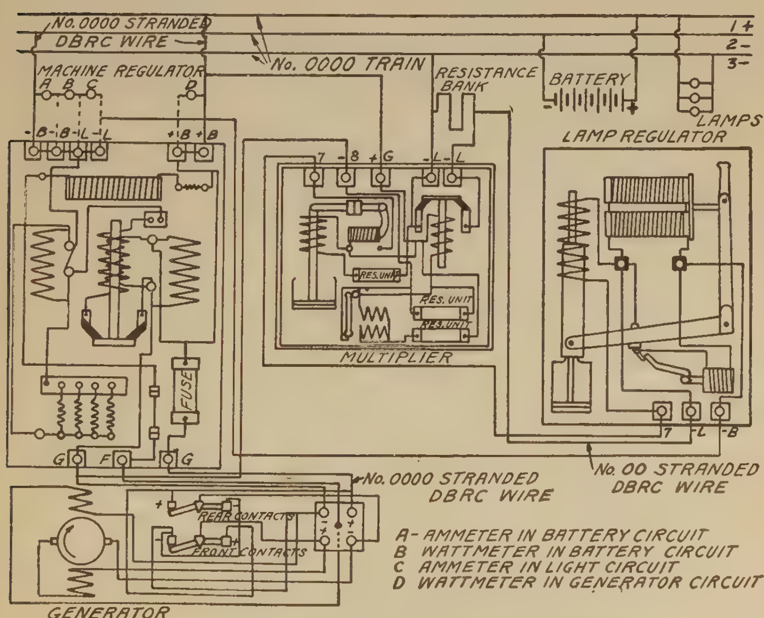


Fig. 55. Connections for Gould Simplex Head-End Equipment

a battery and to operate lamps. It has a main generator switch, *S*, a reverse current circuit-breaker *CB*, an ammeter to give generator output, *GA*, one to indicate lamp load current, *LA*, a voltmeter to indicate lamp, battery, and generator volts, and a resistance in lamp circuit, *LR*, by means of which lamp voltage is controlled.

Operation. Crack main steam valve, open drips, and let steam blow through prime mover to heat it up. Then close drips, open main valve, and bring generator up to speed. Read battery voltage, close circuit-breaker, adjust generator voltage by means of field rheostat to one-half volt more than battery voltage, and close main switch. Adjust generator field rheostat until desired charging current flows to battery. During this starting it is advisable to check lamp voltage from time to time and to hold it constant by resetting lamp circuit resistance.

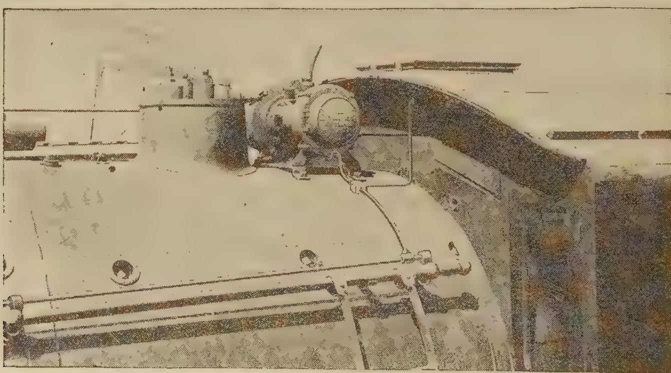


Fig. 56. Turbo-Generator for Engine Head-End Lighting System
Courtesy of The Pyle-National Company, Chicago, Illinois

Axle-Driven Head-End System. The Gould Coupler Company manufactures a head-end lighting system, the regulator members of which, both as to generator control and lamp voltage regulation, are substantially the same as that of the standard Simplex outfit, excepting for larger capacities and higher voltages. The generator is slightly compounded, has interpoles, is chain-driven, operated between 300 and 2100 r.p.m., and is rated as 20 kw. at 80 volts. The train connection composes the standard 3-wire line, with batteries connected to the common positive and

the middle negative; while the lamp loads are connected to the common positive and the outside negative. The connections of this equipment are shown in Fig. 55. The adjustment of this outfit, the possible troubles with it, and means for their detection are the same as considered in connection with the Simplex equipment on pages 54 and 55.

Locomotive Head-End Lighting System. Locomotive illumination for headlight and cab lamps is frequently supplied by electric current. One of the simplest systems comprises a small turbo-generator equipment mounted on the boiler just ahead of the cab. This equipment comprises a high-speed steam turbine operating at about 100 pounds' steam pressure and at 2400, 3600, or 4800 r.p.m., driving a small bipolar generator. The headlight is usually a small arc lamp with focusing coils and large reflector. The cab lighting comprises three to four incandescent lamps. The apparatus is simple, rugged, and easy to maintain. The appearance of a standard equipment is shown in Fig. 56.

MAINTENANCE OF EQUIPMENTS

The action of the regulators, their adjustment, and the troubles which may occur to them have already been considered in the preceding sections. This section will therefore be devoted to the consideration of the maintenance of suspensions, generators, and batteries.

Suspensions. These should frequently be examined to see that all nuts, bolts, and other fittings are tight and securely locked. All suspensions or rocking points should be regularly inspected and lubricated. Plug openings or grease cups are provided in all cases for this purpose. The lubricant may be heavy oil or graphite paste, as directed by the installing company. At such times as the generator is given its periodic overhaul, all suspension pivots, bushings, etc., should be examined for wear and all worn parts should be replaced, as their continued use will cause loss of alignment and excessive belt wear.

Generator Inspection. At the end of long runs the generator should be examined so as to determine if the pulley is on tight. This condition is important because a loose pulley will throw out the alignment and shorten the life of the belt. The pulley should

be secured. Bearings should be examined to see that they have not been cut and that there is sufficient lubricant present. The commutator should be examined for signs of wear, sparking, etc. If the indications of sparking are pronounced, the generator should be examined for high mica between the commutator bars, open coils, or defective brush settings. The brushes should be lifted and the appearance of their contact surfaces noted. If they do not fit properly they must be ground in. The commutator and armature as well as the fields should be looked over for signs of overheating, and if such is apparent the causes should be located and removed.

Sparking. The causes of sparking are:

1. Improper brush setting
2. Overload on machine
3. Open coil in the armature winding
4. High mica between commutator bars
5. Worn, rough, or eccentric commutator
6. Dirty commutator
7. Improper fit between brushes and brush holder

Items 1, 4, 5, 6, and 7 are apparent upon inspection and should be remedied. Brushes must be aligned parallel to the bars. In the case of 2-pole machines, there must be 180 degrees between centers of the brush sets, and in the case of 4-pole machines, there must be 90 degrees. In the case of commutating-pole machines, the brushes must be set to commutate coils exactly under the center of interpole, and in the case of non-commutating-pole machines, the brushes must be given proper angle of lead for sparkless commutation. This angle of brush lead can only be determined by test, and when rotating brush sets are used the stops must be so set that this condition obtains as the brushes are rotating.

Overload on the machine should not occur unless the regulating apparatus fails to function or short-circuits occur in the generator wiring between the generator and the regulating apparatus; consequently this wiring should be examined for grounds and short-circuits.

Open coil in the armature winding will produce pronounced burnt spots on the commutator bars on either side of the open

coil. But sometimes if the coil has been open for a considerable period the commutator becomes so damaged that the open coil cannot be located by inspection. The exact location of the open coil may be determined by the following simple test: Pass current through the armature from the plus to the minus brushes (this current may be about half-load current) and with a voltmeter measure the drop in voltage from bar to bar. When the terminals of the voltmeter span commutator bars which are connected to sound coils, the voltage reading will be extremely small; if, however, the terminals are connected across the bars of the open coil, or coils, the voltmeter readings will be substantially those of the test voltage across the brushes of the machine. Temporary repairs may be made by placing a strap across the two open bars. High mica which may be felt by the finger nails or a quill should be cut down. Worn, rough, or eccentric commutators can only be corrected by turning down. Dirty commutators must be cleaned. Wrong-fitting brushes or brush-holders must be replaced.

Overheating. The causes of overheating of the generator are:

1. Rubbing of the armature upon the pole-core faces
2. Short-circuited armature coils
3. Excessive bearing friction
4. Belt slippage
5. Too much brush friction
6. Sparking
7. Overload

The particular trouble should be located and removed. Whether or not the armature rubs upon the pole cores may be determined by exciting the field winding and rotating the armature by hand. The trouble may be caused by loose pole cores, by a slightly bent shaft, or by foreign material in the air gap of the machine. If this rubbing is noticed the exact cause must be determined and eliminated.

To locate short-circuited armature coils may call for a special test, though if the short-circuit is pronounced, the coil may be located by inspection, as its insulation will be charred and differ in appearance from its companion coils. A short-circuited coil may be exactly located by a bar-to-bar test as follows:

Connect four or five dry cells in series (or several small storage batteries), and put them in series with an ammeter. Con-

nect the free end of the ammeter to a steel testing prod, and the free end of the battery to another testing prod. Press these testing prods upon adjacent commutator bars and note the current. Continue this on all adjacent commutator bars around the armature. When the test prods are pressed upon the bars at the terminals of the short-circuited coil the current, as indicated by the ammeter, will be much greater than that in the other instances. A temporary repair for a short-circuited coil may be made by cutting the coil from its commutator bars and connecting the bars of the coil together by a small strip of copper secured to both of them.

Bearing friction may be detected by turning the machine by hand with belt off. If friction is present it must be removed. Too much brush friction is caused by too great a tension on the brushes. This tension should not exceed from $1\frac{3}{4}$ to 2 pounds as a maximum.

The causes of sparking, their determination, and correction have been given.

The causes of overloading, with a generator designed to operate with a system, have been given. If the generator is too small for the equipment, it should be removed and replaced.

Storage Battery Inspection. The storage battery should be inspected from time to time (a) to determine specific gravity of the electrolyte; (b) to correct for evaporation of electrolyte; (c) to see if the cells are cracked or losing electrolyte by leakage; (d) to note that all battery connections are firm and not being affected by corrosion. The voltage of cells should be frequently read to determine that none are short-circuited, sulphated, or reversed.

The specific gravity of the electrolyte of a storage battery of a lead type is the best indication as to whether the cells are charged or discharged. If one cell of a group is found with low specific gravity while the others are high, it would indicate that this cell is short-circuited and suffers from internal discharge or that it is sulphated. Such a cell should be removed from the battery and be replaced by a sound one. The specific gravity readings are also of considerable value if an ampere-hour meter is used, and from time to time such readings should be taken to determine if the ampere-hour meter and the battery charge are in

step with each other; if they are not, steps should be taken to reset the ampere-hour meter. This may be done most readily by giving the battery a gassing charge and setting the ampere-hour meter index to the full charged point. Correcting for evaporation is very important, because exposure of the plates injures them and decreases the capacity of the battery. When correcting for evaporation use only distilled water and see that the plates are covered with at least one-half inch of electrolyte. Care should be taken not to spill the water between cells as this may cause grounds. Test all connections of the cells to see if any bolts have worked loose, and if they have draw them up tight. If any contacts are corroded, open them up, scrape them clean, remake them, and coat them with an acid-resisting paint. Examine all battery jars and cells to see if they are thoroughly clean, that there is no accumulation of dirt or acid on their covers, and that none are cracked. If any are cracked or broken they must be removed. The battery compartment, or tank, must be examined from time to time to see that there is no accumulation of dust or dirt in it which may cause battery grounds, and that the material of the tank is not being injured by acid spray or accumulation of electrolyte upon its surfaces. It is a good practice to remove the battery from the battery box every six months, and then to dry the same thoroughly and give it at least one coat of acid-resisting paint. If voltage readings on cells indicate that some are of excessively low voltage, these must be removed and the difficulty located. The low voltage may be caused by (a) internal short-circuit due to excessive sediment in the bottom of the cell; (b) failure of separators; (c) buckling of the plates, making them touch each other; (d) sulphation which has been caused by the preceding difficulties or by insufficient charging. The use of battery water containing iron will make cells lose capacity, and only pure water should be used. The cells should be opened up, the plates removed, and the sediment flushed out; defective separators should be replaced; buckled plates should be straightened out by pressure; the repaired elements with their separators should be replaced in the cell and the battery given a series of charges and discharges at moderate rates until it recuperates.

AMPERE-HOUR METER

The ampere-hour meter is an electrical instrument which measures the quantity of electricity that has passed in a circuit, and which indicates the amount in ampere hours. If such an instrument is placed in a battery circuit it may be arranged to indicate the ampere hours which the battery has given out on discharge at any time; and, similarly, if a battery is charged, the ampere-hour meter would, by its reversed rotation, indicate the number of ampere hours put back, reaching zero-discharge position when the battery is recharged. The device is a valuable adjunct in battery work, as the operator can determine the state of battery discharge by looking at the dial of the meter.

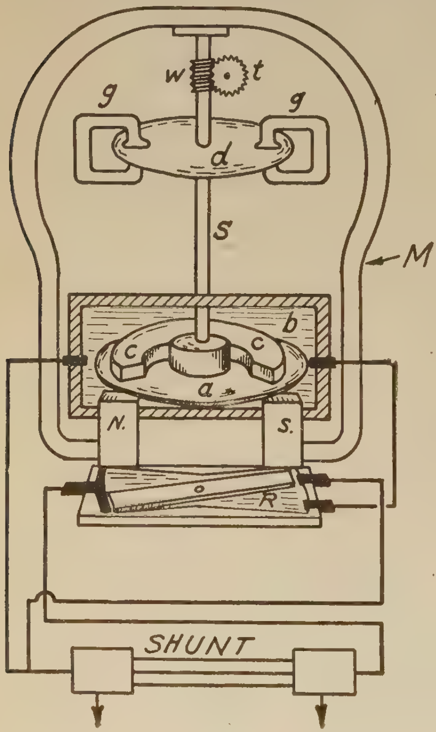


Fig. 57. Schematic Arrangement of Sangamo Meter

Sangamo Ampere-Hour Meter. The ampere-hour meter used in railway-train work must be a rugged one, and must be designed on such principle that vibration will not interfere with the passage of the current from the fixed members to the rotating member, as this would affect the accuracy of the instrument. The most successful type of ampere-hour meter for axle lighting systems is that manufactured by the Sangamo Electric Company.

The most essential members of the Sangamo ampere-hour meter are shown in Fig. 57. They are: a disc-like armature, *a*, which floats in a mercury bath, *b*, under the influence of a permanent magnet *M*, the return path of flux from one magnet pole to the other being by way of the laminated annular core *c*; a damping disc *d*, acted upon by two small permanent magnets *g*;

a shaft S joining the armature M and the disc d; and a worm thread W on the shaft engaging a gear train t. The current path is from a fixed contact in the walls of the mercury container through the disc to the diametrically opposite fixed contact m. The armature disc, therefore, has a turning effect acting upon it which will cause it to rotate. The force acting upon a conductor when it carries an electric current in a magnetic field is proportional to the field strength and the value of the current. If the field strength is of constant value as in the case of the Sangamo meter, the force tending to move the conductor is proportional to the current, hence in the above meter when a current flows through the armature a turning effort or torque is exerted upon it directly proportional to the current in the circuit. The damping disc d, however, rotating between the poles of the magnets g, acts as a generator to retard the rotation of the armature. The retarding effect of this latter disc is proportional to its speed, hence the speed of the moving element, neglecting frictional effects, is proportional to the torque of the main armature, which in turn is proportional to the current. Consequently, the speed with which the mechanism revolves is a measure of the current passing through the armature. The worm thread W on the shaft drives a gear train, which integrates the revolutions and time; thus, an index driven by the train, moving over a suitable dial, would indicate ampere hours.

Use of Variable Shunt. The ampere-hour meter as described above, however, would not suffice to show the state of battery charge between successive discharges and charges, because no battery has an ampere-hour efficiency of 100 per cent, consequently more charge must be put into a battery than can be taken out; or, when a charging current of given magnitude flows through the ampere-hour meter, the rotation must be slower than when a discharging current of the same value flows through it, if the index should arrive at zero indication upon completion of charge. This reduction of speed on passage of a charging current may be secured in various ways. The simplest method is the variable shunt or variable resistor placed in parallel with the armature circuit proper. When a discharge current is passing, the resistor has its maximum resistance and the major part of the

current flows through the armature; when a charging current is flowing and the meter rotates in the reverse direction, the resistance of the resistor path is reduced and the current through the armature is diminished, a larger portion flowing through the resistor path than before, hence the meter runs slower. This resistor element, shown at *R* in Fig. 57, consists simply of a copper bar floated in mercury, its electrical circuit being in parallel with that of the armature. This floating copper bar being placed under the influence of the field of the magnet *M*, tends to rotate in the same direction as the armature disc. This rotation is limited to an angle of 45 degrees to correct for minimum ampere-hour efficiency of the battery or to produce maximum difference

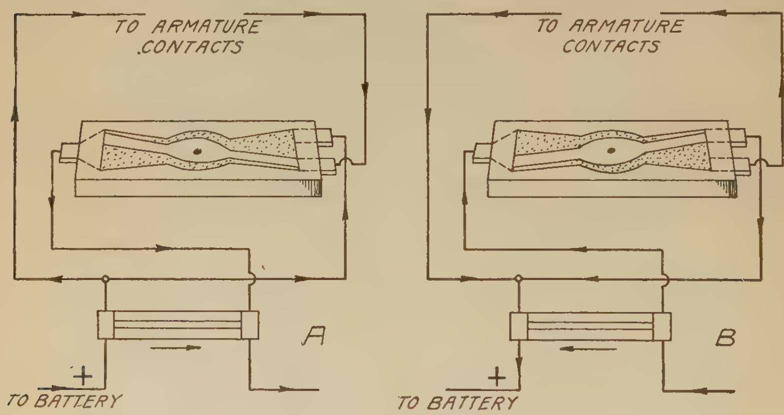


Fig. 58. Resistor Connections of Sangamo Meter

in charge and discharge speeds of the meter. The usual setting is based on an ampere-hour efficiency of 80 per cent or the meter runs 20 per cent slower on charge than when measuring a discharge current. The exact circuit connections of the resistor are as shown in Fig. 58 at *a* and *b*. When the battery is discharging the vane is moved clockwise and sends the larger portion of the current through the armature of the meter as shown at *a*. When the battery is charging, the vane moves in a counter-clockwise direction and more current flows through the resistor shunt path and a reduced current through the armature of the meter, as indicated at *b*. The appearance of a typical train equipment Sangamo meter is shown in Fig. 59. The contacts

operating the stop-charge connections may be seen through the cut-out back of the indicator hand.

In railway train-lighting work the ampere-hour meter is not only used as an instrument to show state of battery charge, but it is also used, as already explained, to stop overcharge by acting upon the voltage coil of the generator regulator to reduce generator voltage to a battery-floating value. This control element is introduced by two contact points which are closed upon each other by the pressure of the meter hand when it reaches zero-discharge position. Closure of these contacts modifies the connections of the voltage coil of the regulator so that it may function to cut down the generator voltage.

Use of Thermocouple. Storage batteries lose about 3 per cent of their charge for every 24 hours when they stand idle. As this loss of charge is not accompanied by a flow of current from the battery through the meter, the same does not correctly indicate the state of battery charge. To overcome this difficulty a thermocouple is introduced, which is connected across the meter terminals. This thermocouple is surrounded by a very small heating coil, and thus a low difference in potential is developed by the said thermocouple. This being applied across the armature circuit of the meter causes it to revolve slowly in the discharge direction at a speed corresponding to what the leakage loss would be. This thermocouple also plays a part in overcoming friction, so that light load readings are more accurate than they would be without its effects.

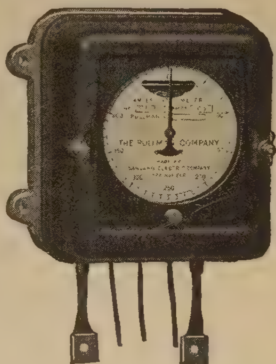


Fig. 59. Sangamo Auto-Base Ampere-Hour Meter with Variable Resistor, as Built for Pullman Company

Courtesy of Sangamo Electric Company, Springfield, Illinois

Meter Troubles. *Testing Readings.* If the inspector is in doubt as to the accuracy of the indications of the ampere-hour meter, the meter should be tested. This is very readily done, the only instruments required being an accurate ammeter and a stop watch. Connect the ammeter, if of the internal-shunt in series type, with the ampere-hour meter, or, if it is of the external-shunt type, connect the shunt in series with the ampere-hour

meter and test the meter on discharge. This may be done by putting on the lamp load; or, if this is not sufficient to give close settings on the ammeter, an adjustable rheostat may be connected across the line. The speed of the meter in the discharged direction is 10 revolutions in 36 seconds at full load. In taking a check on the meter accuracy the following formula should be used: $S=\frac{KR}{I}$ wherein K is the meter constant, R the revolutions observed, I the load in amperes, and S the correct time in seconds for the revolutions observed. If the observed time does not correspond with the time as calculated from the given formula, the percentage of meter accuracy can be determined by dividing the correct time by the observed time; in other words, if T is the observed time, the percentage of meter accuracy will be S divided by T. The constant of a 10-ampere meter is 36, and it is directly proportional for other sizes unless it is marked otherwise on the meter. Thus in the case of a 40-ampere meter the constant would be 144. Full-load adjustment on the meter is obtained by varying the position of the laminated iron discs located above the jaws of the permanent magnet. Raising the disc decreases the speed of the meter; lowering increases it.

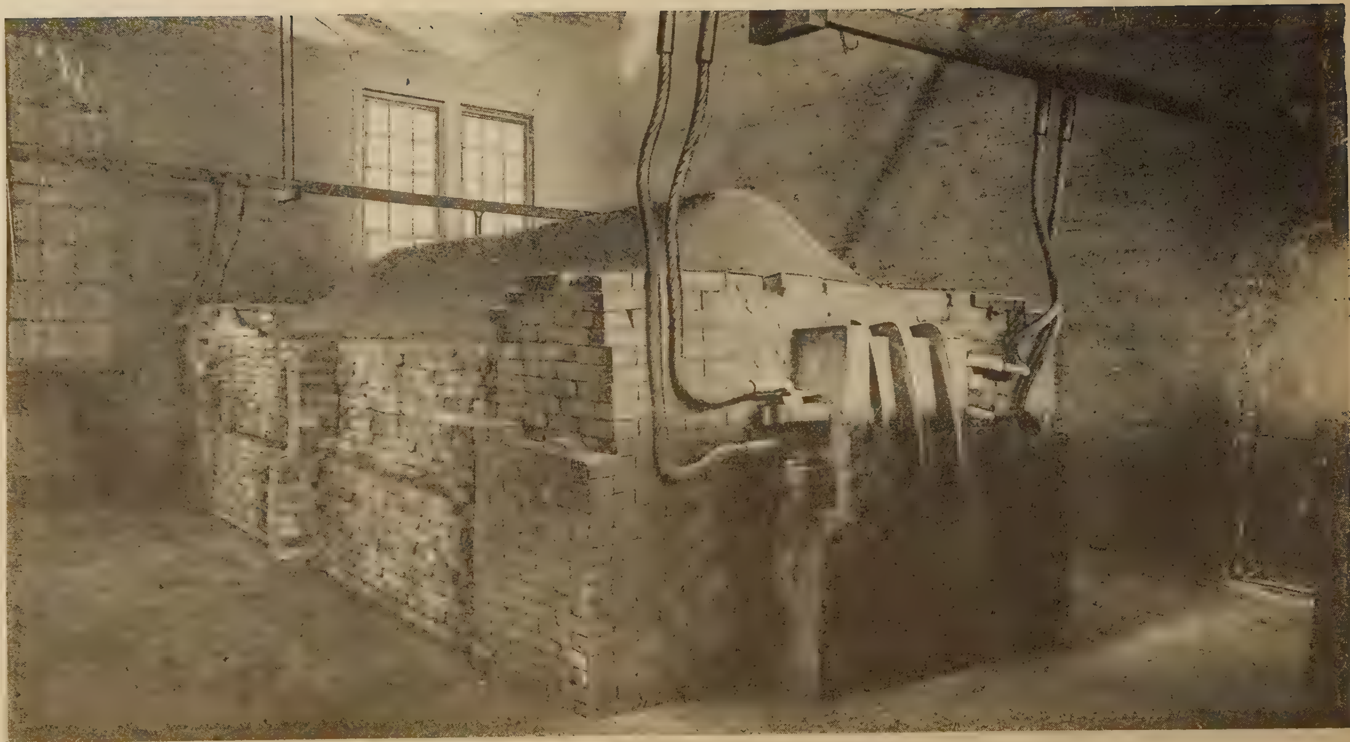
The accuracy of one of these meters is within 3 per cent when operating at light load, which is assumed to be 10 per cent of the meter capacity. Unless the meter is equipped with the thermocouple, there is no adjustment for the light load accuracy, and if the error at this load exceeds 3 per cent, it is advisable to clean the meter thoroughly. Very often it is found that filings or other foreign material are in the air gaps of the magnets and drag upon the damping disc, reducing the motor speed. Therefore before undertaking to disassemble the meter these gaps should be thoroughly cleaned.

Meter Running Slow or Fast. A meter may run slow because of (a) friction; (b) poor connection at armature case terminals; (c) weakening of main magnet; (d) sticking of variable resistor in the charged position; (e) soft iron disc of main magnets set too low.

A meter may run fast because (a) connections at the terminals of the resistor are loose; (b) soft iron ring of main magnets is too close to the disc; (c) damping magnets are weakened.

The friction may be caused, as explained, by dust or dirt on the damping disc or damping magnets, by defective jewel bearing at the top of the meter, by the mercury in the main armature, or by the resistor chambers being dirty.

Checking Resistor. The resistor can be readily checked by setting it for zero overcharge. If it was originally stuck in the charged position, this movement of the resistor back to zero overcharge will cause the vane to be moved into the discharged position. Pass current through the meter again and time it. If the meter now has the correct speed, it is apparent that the trouble is in the resistor. In that case the meter should be sent to the shop for repair. If, however, the meter is still operating slow when the resistor has been moved, this is an indication that no trouble existed there. The correction for slow running, then, should be made by moving downward closer to the magnet poles the soft iron disc above the armature. This adjustment should not be attempted until all other causes for friction have been examined and eliminated. If the meter is running too fast, first see that the connections of the terminals of the resistor are tight, and if these are all right, adjust the disc above the main magnet to reduce the speed. This may be done by raising the disc slightly. If the meter runs fast at light load, this is probably due to the damping magnets being weakened or to the thermocouple giving too much current. The thermocouple effect may be corrected by putting a little more resistance in series with it and the armature terminals to reduce the current set up by it.



AN ELECTRIC FURNACE PREPARED FOR ACTION
Courtesy of The Carborundum Company, Niagara Falls, N. Y.

APPLIED ELECTROCHEMISTRY

INTRODUCTION

Chemical Reactions. Chemical reactions are frequently, if not in fact almost universally, associated with changes in electrical energy. The science and art of electrochemistry deal with the relationship of electrical and chemical forms of energy. It is well known that many chemical reactions take place with the liberation of energy in the form of heat; thus when coal burns, combining with the oxygen of the air, there is a liberation of heat energy. Certain other chemical changes involve an absorption of heat energy, that is, heat must be applied to materials in order to cause certain reactions to take place. The formation of calcium carbide is an example of the production of a useful compound by heating lime and carbon to a high temperature. All chemical reactions may be classified as either *endothermic*—heat-absorbing reactions—or as *exothermic*—heat-liberating reactions.

Numerous chemical transformations also occur with a liberation of electrical energy, a fact upon which are dependent the various types of primary cells or electric batteries. Electrical energy may, on the other hand, be made to produce chemical changes by the passage of electric current through an electrolyte, and this finds practical application in various forms of electrolytic cells.

Storage batteries constitute an important class of electrical apparatus, consisting of a certain combination of metals and electrolyte in which the electrochemical action is reversible, that is, in passing current through the battery in one direction certain chemical changes take place, or the battery is stored or charged, and these chemical reactions take place in a reverse direction when the current is allowed to flow in a reverse direction, as when the battery is discharged.

Range of the Subject. The fundamental units and principles of electricity, the elementary principles of electrochemical action, the primary cell, and the secondary, or storage, cell have already been considered in previous articles, and consequently this article

will be confined to a consideration of the wider field of applied electrochemistry, dealing with the more important practical uses of electrical energy in producing useful chemical transformations.

Electrical energy may be applied to materials by various methods, the more important of which are the following:

(1) Electrolysis, or the electrolytic change brought about by the passage of a direct current through an electrolyte.

(2) Electrothermics, or the production of chemical change through the heat effect produced by electrical means.

(3) Electrical discharge in gases.

ELECTROLYSIS AND ITS APPLICATIONS

ELECTROCHEMICAL THEORY

KINDS OF CONDUCTORS

All materials may be divided, first, into two classes, depending upon whether or not they conduct electrical current. If they conduct, they are called "conductors" and if they do not, they are designated as "insulators". In turn, materials which conduct may again be subdivided into two more classes commonly designated: *metallic conductors*, or *conductors of the first class;* and *electrolytic conductors*, or *conductors of the second class.*

It is important that as a basis for the study of electrolysis a clear idea be acquired as to the distinctive differences between metallic and electrolytic conductors.

Metallic Conductors. As implied by the name, *metallic conductors*, the metals belong to this class; and in addition to the metals and metallic alloys, there are a few other elements and various compounds which conduct in a similar manner and are therefore designated as metallic conductors. In this class of conductors the flow of current produces only a heating effect without producing chemical change.

Non-Metallic Elements. Of the few non-metallic elements which conduct, the most important is carbon, or graphite. Silicon, boron, and selenium are other elements possessing metallic conductivity to some degree.

Classification. Electrolytic conductors may be either fused materials or certain solutions of materials in water or other solvents. Some evidence of electrolytic conductivity has been detected in a few solid compounds, but this phenomenon is of little importance from the practical standpoint. It is with liquid conductors that electrolysis commercially applied has to deal and for practical purposes these liquid conductors may be placed in three divisions:

(1) Electrolytes consisting of substances dissolved in water.

(2) Electrolytes consisting of substances dissolved in solvents other than water.

(3) Electrolytes consisting of chemical compounds in a state of fusion.

The first group is the one of the greatest importance, since water is a great universal solvent, which, on account of its abundance and low cost and great solvent properties, furnishes an essential material in most industrial electrolytic processes. Non-aqueous solutions, while attracting much interest from the theoretical and scientific points of view, have as yet few technical applications. A more extensive use of these solvents, however, may safely be anticipated as a result of future development.

Electrolytes consisting of fused materials have important technical applications in industries such as the manufacture of aluminum, sodium, magnesium, and calcium.

Water, in a high state of purity, possesses very little conductive power; in fact it is practically an insulating material. Kohlrausch gives a specific resistance of 25,000,000 ohms per $\overline{\text{cm}}^3$ for freshly distilled water. On accumulating impurities by exposure to the air for some time, the resistance may drop to one-twentieth of this amount.

Similarly, sulphuric acid, in a condition of absolute purity, has an exceedingly high specific resistance, tending to place it among the insulators. If, however, a certain amount of these two non-conductive substances be mixed together, the result is a material which has a power of conducting to a high degree. The question has naturally arisen as to whether it is the acid under the influence of the water or the water as influenced by the acid, or a combination of both, which produces the conductive power. In settling this point, we would be led into the realm of speculation and, for practical purposes in working with aqueous electrolytes, the common assump-

tion may be followed that it is the substance which is dissolved in the water which possesses the conductive property.

Conductivity. One important characteristic of electrolytic conductors is that the order of conductivity is far lower than that of metallic conductors. The best conducting electrolytes, for example, have a specific resistance at least one million times as great as that of the average metallic conductor.

Another striking characteristic is the negative temperature coefficient which causes the resistance to decrease with increasing temperature.

It should be borne in mind that by no means all of the materials which dissolve in water produce electrolytes. Those chemical substances which on dissolving in water become conductive have been determined by trial and by measurements. Sugar and common salt are both soluble in water. The former, however, produces no electrolytic conductivity, while the latter does.

It has been found by trial that, in general, solutions of inorganic acids, salts, and bases conduct electrolytically, while the neutral organic compounds in solution do not conduct.

The degree of conductivity of an electrolyte depends upon a number of factors, including the chemical composition of the dissolved substance, the amount of such substance in solution, and the temperature.

A quantitative study of the relationship between the conductivity of a solution of a given substance and the amount of substance dissolved, reveals interesting and important features and furnishes the basis upon which modern theoretical views of electrolytic dissociation and conduction are based. However, for practical purposes of an elementary text, it may not be necessary to follow this line of study here.

THE ELECTROCHEMICAL CELL

Definitions. An *electrochemical cell* is a form of apparatus in which all industrial electrolytic processes are carried out. It may be defined as a combination of two metallic conductors, constituting the *electrodes,* and an electrolytic conductor, constituting an *electrolyte* which joins the electrodes. A suitable containing vessel is also an essential part.

The *anode* is the electrode at which the current enters the electrolyte, and the *cathode* is the electrode at which the current leaves the electrolyte.

The cell is *inactive* if no current flows, and it becomes *active* when the current passes, which in turn means that to be active it must be connected to an external source of electrical energy. This external energy may be obtained from any generator of direct current, such as a primary battery, a storage battery, or a dynamo.

Action Inside the Cell. *Diagram of Circuit.* A typical diagram of an active cell is shown in Fig. 1, where *d* is the dynamo, or other source of current; *r* is a rheostat for regulating the amount of current, or current density; *i* is an ammeter for measuring the current; and *v* is a voltmeter for measuring the voltage at the cell terminals; *s* is a switch for opening or closing the circuit. The arrows indicate the direction of the flow of current; *a* is the anode, and *c* the cathode.

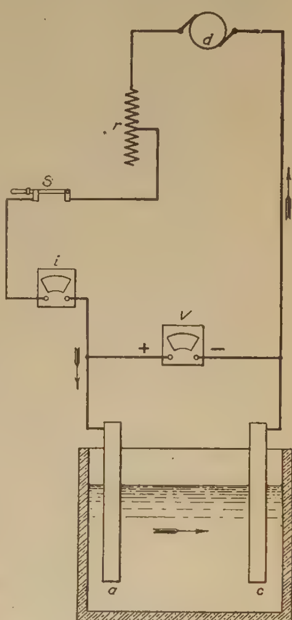


Fig. 1. Diagram of Electrolytic Cell

It will be noted that the positive (+) terminal of the voltmeter is connected to the anode, or positive pole, at which the current enters the cell, while the negative (−) terminal of the voltmeter is connected to the cathode, or negative pole. For this reason it is a common practice to use the terms "positive pole" and "negative pole" in place of the terms "anode" and "cathode", respectively. To avoid confusion, however, it is far better to employ the terms *anode* and *cathode* wherever possible and to learn to know instinctively that the anode designates the surface at which the current enters the electrolyte and that the cathode indicates the surface where the current leaves.

Method of Carrying Current. To determine in just what manner the electrolyte carries the current is the purpose of various theories which are not as yet capable of positive proof. It is a common con-

TABLE I

Positive and Negative Radicals of the More Common Compounds

SUBSTANCE	FORMULA	NEGATIVE RADICAL OR ANION	POSITIVE RADICAL OR CATHION
Aluminum chloride	$AlCl_3$	3Cl	Al
Ammonium chloride	NH_4Cl	Cl	NH_4
Barium chloride	$BaCl_2$	2Cl	Ba
Calcium chloride	$CaCl_2$	2Cl	Ca
Potassium chloride	KCl	Cl	K
Cadmium chloride	$CdCl_2$	2Cl	Cd
Magnesium chloride	$MgCl_2$	2Cl	Mg
Manganese chloride	$MnCl_2$	2Cl	Mn
Sodium chloride	NaCl	Cl	Na
Hydrochloric acid	HCl	Cl	H
Zinc chloride	$ZnCl_2$	2Cl	Zn
Hydrobromic acid	HBr	Br	H
Potassium bromide	KBr	Br	K
Hydriodic acid	HI	I	H
Potassium iodide	KI	I	K
Barium nitrate	$Ba(NO_3)_2$	$2NO_3$	Ba
Calcium nitrate	$Ca(NO_3)_2$	$2NO_3$	Ca
Nitric acid	HNO_3	NO_3	H
Potassium nitrate	KNO_3	NO_3	K
Silver nitrate	$AgNO_3$	NO_3	Ag
Sulphuric acid	H_2SO_4	SO_4	2H
Copper sulphate	$CuSO_4$	SO_4	Cu
Magnesium sulphate	$MgSO_4$	SO_4	Mg
Sodium sulphate	Na_2SO_4	SO_4	2Na
Silver sulphate	Ag_2SO_4	SO_4	2Ag
Zinc sulphate	$ZnSO_4$	SO_4	Zn
Potassium carbonate	K_2CO_3	CO_3	2K
Sodium carbonate	Na_2CO_3	CO_3	2Na
Potassium chlorate	K_2ClO_3	ClO_3	2K
Potassium hydroxide	KOH	OH	K
Sodium hydroxide	NaOH	OH	Na
Potassium chromate	K_2CrO_4	CrO_4	2K
Potassium bichromate	$K_2Cr_2O_7$	Cr_2O_7	2K
Potassium cyanide	KCN	CN	K
Potassium ferrocyanide	$K_4Fe(CN)_6$	$Fe(CN)_6$	4K
Potassium silver cyanide	$KAg(CN)_2$	$Ag(CN)_2$	K
Potassium oxalate	$K_2C_2O_4$	C_2O_4	2K
Sodium acetate	$NaC_2H_3O_2$	$C_2H_3O_2$	Na

ception that the current in passing through the electrolyte causes a bodily movement of some of the material in the electrolyte in the direction of the current and of a corresponding amount of other material in the reverse direction. Or, in other words, the materials held in solution dissociate into ions. Those *ions* which travel with the current and are deposited on the cathode are called *cathions* and those which go against the current and are liberated at the anode are *anions*.

Anions and Cathions. In order to determine what action will take place in a cell, it is important to know what materials constitute the anions and cathions.

From a study of chemistry, it is noted that the inorganic compounds such as are taken into solution in water, are composed of what are known as the *metal,* or *positive, radical* and an equivalent *acid,* or *negative, radical.* Table I gives a list of the more common materials with their respective anions and cathions.

From this table it is to be noted that the cathions consist almost entirely of metals, with the addition of the element hydrogen and of the compound NH_4; also that the anions consist of the electronegative elements, such as chlorine, bromine, iodine, and fluorine, and of various compound radicals, such as SO_4, NO_3, CO_3, OH, CrO_4, etc.

Faraday's Laws. The most important laws pertaining to electrolysis are what are known as Faraday's laws. They constitute the basis of all electrochemical calculations, determining just how much chemical action is produced by a given flow of current for a given time. These laws are as follows:

(1) The amount of chemical effect produced during electrolysis is directly proportional to the product of the current and the time; that is, to the quantity of electricity which flows through the electrolyte.

(2) When a current passes through an electrolyte, bringing about chemical changes at the electrodes, the quantity of each substance formed is directly proportional to the equivalent weight of the substance and to the quantity of electricity which has flowed through the electrolyte.

It is obvious that if one ampere flowing for one minute will deposit a certain amount of copper, two amperes flowing for one minute will deposit twice that amount. Also that the amount which a given current will deposit in ten minutes is ten times as great as will be deposited by the same current in one minute.

Electrochemical Equivalent. By knowing the *equivalent weight,* or, as it is more commonly termed, the chemical equivalent, of the material, the quantity of that material which will be liberated by a known amount of electric current can be readily calculated. Every substance, whether it be a chemical element or a chemical compound, has its *electrochemical equivalent,* just as it has a certain atomic

TABLE II

Constants of the Elements*

Name of Elements	Symbol	Valency	Chemical Constants		Electrochemical Constants			Commercial Constants "Result"	
			Atomic Weights	Chemical Equivalents	Per Coulomb (i. e. per amp. sec.) in mg. per sec.	Per Ampere Hour (i.e. 3600 Coulombs) in grams	Per Faraday (i.e. 96,540 Coulombs), grams	Per 1000 Ampere Years (i.e. 8760 hrs.) in metric tons	Per H. P. Year for one volt in metric tons
Aluminum. . . .	Al	III	27.10	9.03	.09354	.33674	9.033	2.950	2.201
Antimony.	Sb	III	120.20	40.07	.41509	1.4943	40.067	13.090	9.765
Arsenic.	As	III	75.00	25.00	.25898	.93233	25.000	8.167	6.093
Barium.	Ba	II	137.40	68.70	.71166	2.5620	68.700	22.443	16.742
Bromine.	Br	I	79.96	79.96	.82831	2.9819	79.960	26.221	19.561
Cadmium	Cd	II	112.40	56.20	.59229	2.1322	56.200	18.678	13.934
Calcium.	Ca	II	40.10	20.05	.20770	.74772	20.050	6.550	4.886
Carbon.	C	IV	12.00	3.00	.031077	.11188	3.000	.9801	.7311
Chlorine.	Cl	I	35.45	35.45	.36723	1.3220	35.450	11.581	8.639
Cobalt.	Co	II	59.00	29.50	.30559	1.1001	29.500	9.637	7.189
Copper.	Cu	II	63.60	31.80	.32942	1.1859	31.800	10.388	7.749
Fluorine.	F	I	19.00	19.00	.19682	.70855	19.000	6.207	4.630
Gold.	Au	III	197.20	65.73	.68090	2.4512	65.733	21.473	16.019
Hydrogen.	H	I	1.008	1.008	.010442	.03759	1.008	.329	3.2456
Iodine.	I	I	126.97	126.97	1.3153	4.7351	126.970	41.479	30.943
Iron.	Fe	II	55.90	27.95	.28953	1.0423	27.950	9.131	6.812
	Fe	III	55.90	18.63	.19279	.69404	18.633	6.090	4.543
Lead.	Pb	II	206.9	103.45	1.07164	3.8579	103.450	33.795	25.211
Magnesium. . .	Mg	II	24.36	12.18	.12617	.45422	12.180	3.979	2.968
Manganese. . . .	Mn	II	55.00	27.50	.28587	1.0291	27.500	9.015	6.725
	Mn	III	55.00	18.33	.18988	.68357	18.333	5.988	4.467
Mercury	Hg	I	200.00	200.00	2.0718	7.4585	200.000	65.333	48.738
	Hg	II	200.00	100.00	1.0359	3.7292	100.000	32.667	24.370
Nickel.	Ni	II	58.70	29.35	.30404	1.0945	29.350	9.588	7.153
	Ni	III	58.70	19.57	.20273	.72983	19.567	6.393	4.769
Nitrogen.	N	III	14.04	4.680	.048480	.17453	4.680	1.529	1.141
Oxygen	O	II	16.000	8.000	.082872	.29834	8.000	2.613	1.949
Platinum.	Pt	IV	194.80	48.70	.50448	1.8161	48.700	15.909	11.868
Potassium.	K	I	39.15	39.15	.40555	1.4600	39.150	12.790	9.541
Silicon.	Si	IV	28.40	7.10	.073549	.26478	7.100	2.319	1.730
Silver.	Ag	I	107.93	107.93	1.11805	4.02498	107.930	35.267	26.309
Sodium	Na	I	23.05	23.05	.238775	.859590	23.050	7.530	5.617
Sulphur.	S	II	32.06	16.03	.16605	59778	16.030	5.237	3.907
Tin.	Tn	II	119.00	59.5	.61636	2.2189	59.500	19.438	14.501
	Tn	IV	119.00	29.75	.30818	1.1094	29.750	9.718	7.250
Zinc.	Zn	II	65.40	32.70	.33874	1.2195	32.700	10.683	7.970

*From "Electrothermal and Electrolytic Industries", Ashcroft.

weight; and in fact the electrochemical equivalent is closely associated with the atomic weight.

The *electrochemical equivalent* of a substance is the atomic weight divided by the valence and multiplied by a constant. This constant is a weight of hydrogen which will be liberated by a unit quantity of electric current. This constant is .00001036 grams, being the

amount of hydrogen which is liberated by one coulomb or one ampere flowing for one second.

For purposes of practical calculation it is common to express the electrochemical equivalent of a substance in terms of the amount of material which is deposited by one ampere flowing for one hour's time. Table II gives electrochemical equivalents of various common elements.

If, for example, it is desired to know how much copper will be deposited by ten amperes flowing for two hours, a simple calculation based upon the value of copper shown in Table II can be made. It is $10 \times 2 \times 1.1859$, or 23.71 grams. Likewise, the same amount of current will liberate $10 \times 2 \times 1.322$, or 26.44 grams of chlorine.

Cathode Reactions. In observing the changes which take place at the cathode during electrolysis, various phenomena may be noted. If a suitable solution containing copper or nickel is used, copper or nickel will be deposited at the cathode, coating it over and growing to such thickness as is determined by the amount and duration of the current. Likewise, various other metals, such as gold, silver, iron, zinc, cobalt, and cadmium, may be deposited. This furnishes the basis of the electroplating industry. Some of the metals, on the other hand, will not be deposited out in the metallic state; for example, no one has yet succeeded in depositing metallic aluminum, neither can sodium, or potassium, or calcium, or various other highly positive metals be deposited from aqueous solutions. The reason for this is that these electropositive metals, at the instant they are liberated by the current, react chemically with the water to form other compounds. When sodium is deposited, it reacts chemically with the water, in accordance with the following equation:

$$Na + H_2O = NaOH + H$$

Instead, therefore, of metallic sodium being liberated, hydrogen is evolved and caustic soda is formed in the electrolyte. The electrolytic production of caustic soda and of hydrogen is thereby made possible as a result of electrolytic action supplemented by chemical action.

It should be noted, therefore, that the *cathion* may be deposited directly on the cathode, or it may unite chemically with the electrolyte.

Anode Reactions. In a similar manner the *anions,* upon being liberated, may be deposited on the anode, or may escape as a gas, or may react chemically with the electrolyte, or may unite chemically with the electrode material. Which of these various processes takes place depends largely upon the peculiar characteristics of the material involved. It is important to note that the materials at the instant of liberation are in a particularly active chemical condition, or in the nascent state. Perhaps the most noticeable action at the anode is a tendency for the liberated materials to attack or corrode the anode. Thus, for example, when a sodium chloride solution is electrolyzed between two iron electrodes, the chlorine which is liberated at the anode will attack the iron to form soluble iron chloride; in other words, the iron will go into solution. If it is desired to decompose salt for the production of chlorine, an *insoluble* anode material must be selected. Graphite is particularly serviceable for this purpose and is extensively used for chlorine production.

Soluble and Insoluble Anodes. We have then what are known as *soluble* and *insoluble* anodes, depending upon whether they withstand the action of the electrolysis. As a general rule, the metals are corroded when used as anodes. It is for this reason that deterioration of water and gas pipes takes place in the city streets where leakage current from electric railways flows from the iron surfaces into the earth. Dependent upon the anode solubility, the amount of metal in an electroplating solution is maintained at a constant value, the metal going into solution from the anode at the same rate that it is deposited out at the cathode.

Of the various metals, platinum is the one most commonly used when an insoluble metal is required. Graphite is insoluble in chloride solutions, while it is slowly attacked in certain other solutions. Lead peroxide and the black magnetic oxide of iron, previously referred to as being compounds which conduct metallically, have their principal use in electrolytic work because of their electrochemical insolubility.

ELECTROLYTIC REFINING AND RECOVERY OF METALS

Refining Copper. An important use of the electrolytic cell is found in the refining of certain metals, the most important of which is copper. Copper of high purity is necessary as a conductive

material for electric power generation and distribution, and in the early days of the electrical industry, the only source of a sufficiently pure metal was the native metallic copper found in the Lake Superior region and commonly known as "lake" copper. The rapidity of electrical development made this source of supply entirely inadequate and it became necessary to draw upon the enormous deposits of copper ore found in the Western States. By the ordinary metallurgical methods of smelting, however, only an impure grade of copper could be produced, the highest purity not being greatly in excess of 98 per cent. A very small amount of alloying impurity in copper has the effect of greatly reducing its electrical conductivity and, therefore, high purity is of supreme importance. The desire of utilizing these Western ores, therefore, directed attention to the electrolytic method of refining. In fact, practically the only known method of making impure copper available for the electrical industry is by the electrolytic refining methods which have been worked out during the last quarter of a century.

Action in Experimental Cell. A simple experimental cell for refining copper can be constructed easily by dissolving copper sulphate crystals in water, adding a small amount of sulphuric acid, and then passing current through this solution, using an impure copper anode and a copper sheet cathode upon which the pure metal is to be deposited. The amount of copper which is deposited upon the cathode depends mainly upon the amount of current and the time of flow. The SO_4 anion which is liberated at the anode attacks the anode copper, forming copper sulphate and thus replacing the copper which is thrown out at the cathode. The amount of copper which goes into solution should, according to Faraday's laws, be equal to that which is deposited out at the cathode. The resultant action is then simply a transference of the copper from the anode through the solution to the cathode. The refining takes place because certain of the impurities in the anode are insoluble, such for example as silver, gold, and lead. Certain other impurities go into solution in the electrolyte, but are prevented from being deposited at the cathode because copper separates far more easily than do the other elements.

By-Products. The result of this refining operation is that certain of the impurities either remain attached to the anode or settle to

the bottom of the cell as what is known as anode slime. Other of the impurities, such as arsenic and iron, gradually accumulate in the electrolyte until such quantity is reached that it becomes necessary either to throw the electrolyte away or put it through a chemical refining operation.

The electrolytic cell for the refining of metals has been likened to a series of screens through which the desired metal is sifted, leaving the impurities behind.

While the principal object in the refining of copper was to get the pure metal, it was soon noted that some of the impurities which settled to the bottom of the tank were of value, these metals being principally gold and silver. The subsequent recovery of these materials from the anode slimes furnished a great source of profit, and, in fact, copper refining has become important not only for the manufacture of pure copper but for the recovery of precious metals as well.

Refining of Metals Other Than Copper. *Silver.* It must not be assumed that, because copper refining by electrolysis is eminently successful, the electrolytic method may be similarly applied to the other metals. In fact the ordinary metallurgical methods are usually superior as to cost and availability. Electrolytic silver refining is carried out to some extent by what is known as the *Moebius* process, in which the anodes or impure silver bars are suspended in a filter cloth sack in an electrolyte consisting of silver nitrate slightly acidified by nitric acid.

From this electrolyte the silver is deposited in a loose crystalline state which tends to grow in tree-like formations toward the anode. To prevent this, each cathode is provided with a wood scraper which periodically removes the crystalline deposit of pure silver. This settles to the bottom of the tank, where it is subsequently removed.

Gold. Gold refining is likewise carried out to a certain extent, the anodes usually containing about 94 per cent of gold, 5 per cent of silver, and one per cent of copper and various other metals. The electrolyte consists of a solution of gold chloride with a small amount of free hydrochloric acid and a trace of gelatin added to improve the physical quality of cathodic deposit.

Baser Metals. While many attempts have been made toward electrolytic refining of common metals, such as zinc, tin, nickel, and

iron, the difficulties are usually so great, or the other metallurgical methods so satisfactory, as to make the financial reward insufficient to warrant commercial development. The electrolytic refining of iron seems to offer some possibilities of industrial success, due to a certain demand for a specially high-grade material. Most of the electrolytic iron thus far produced has been used only for experimental purposes and in researches concerning the nature of iron and iron alloys.

From the experiments of the earlier electrochemists with the deposition of lead, there was a general belief that lead could not be deposited electrolytically in anything but a loose and spongy form. As illustrating the value of a detailed study of electrolyte materials, reference may be made to the interesting and important discovery that a dense heavy deposit of lead may be obtained by the use of a solution of lead silico-fluoride, $PbSiF_6$, with the addition of a trace of gelatin. This discovery led to the development of what is known as the "Betts Process" for lead refining, which is in extensive commercial use.

Electrolytic Recovery of Metals. One of the alluring prospects which has been held out in connection with electrochemistry is its application to the recovery of metals from the ores. It has been thought by many inventors that the electrolytic methods might compete with the smelting and wet extraction methods constituting general metallurgical practice, but more especially have inventors been directing their attention to the recovery of values from refractory or non-workable ores discarded in current metallurgical practice.

Gold from Sea Water. It has been known for a long time that sea water contains gold in such quantity that a cubic mile of the sea water taken at almost any locality contains a great wealth of this precious metal. It is also known that gold can be deposited from an aqueous solution by the passage of an electric current, and this fact has led to many attempts at the electrolytic recovery of gold from sea water. These attempts have all been failures through neglect to recognize certain fundamental laws of electrolysis. The gold which is in solution is probably present as gold chloride, but in exceedingly dilute solution. If this electrolyte is placed in an electrolytic cell, the gold will migrate very slowly toward the cathode.

The sea water contains chlorides of sodium and magnesium as well as various other dissolved substances and these also act as an electrolytic conductor carrying the current. In passing current then through such a cell, most of the current is consumed in decomposing the more abundant materials to the exclusion of the gold. In figuring the cost of electrical energy, the corrosion of the anode material, and the interest and depreciation of the investment tied up in the cell construction, there is no possibility of a sufficient gold recovery to repay even an exceedingly small fraction of the necessary expense.

Other Metals. Various complex ores of zinc containing lead and silver and certain other elements have resisted treatment by metallurgical methods and have constituted an attractive material for electrochemical work. Many other examples may be named, but as yet no notable commercial success has been achieved in the electrolysis of aqueous solutions for the extraction of metals from their ores. As to the electrolysis of fused electrolytes, the conditions are different, as evidenced by the aluminum industry to be described later.

General Features of a Recovery Process. To treat an ore or a waste product containing a metal necessitates, first, getting it into an aqueous solution. This may be done by treatment with an acid and then dissolving out the soluble compound. The next step is to treat these compounds in an electrolytic cell, depositing the metal upon the cathode from which it can be recovered. While the cost of leaching and extraction usually makes the process prohibitive, there are serious electrochemical difficulties, the chief of which is the difficulty of getting an insoluble and sufficiently cheap anode material. If a soluble anode material be employed, the expense caused by its corrosion may likewise become prohibitive.

The cost of electric energy involved is another important item. If, for example, in the deposition of zinc an insoluble anode be employed, the electromotive force at the cell terminals would be at least 3 volts. One pound of zinc, for example, weighing 456 grams would require 456 divided by 1.219, or about 374 ampere hours. At a pressure of 3 volts this makes a consumption of 3×374, or 1122 watt hours per pound of zinc. The cost of this energy would thus constitute a serious item of expense.

ELECTROPLATING

The most widely extended use of the electrolytic cell is in the art of electroplating. This is the art of coating a surface with a thin layer of dense adherent metal. Gold and silver are used mainly on account of the ornamental properties of these metals, while zinc is employed mainly on account of its protective action. Nickel has both ornamental and protective properties, and in fact each one of the metals capable of deposition has certain properties which give it some value in the electroplating art.

By Simple Immersion. As differing from the art of electrodeposition, we have what is known as the coating by simple immersion, whereby one metal may receive a deposit of another metal by simply dipping it into a solution containing some of the latter metal. For example, in dipping a piece of clean iron into a copper sulphate solution, a coating of copper is quickly produced. Copper when dipped into certain silver solutions, likewise attains a silver coating; and coatings of gold are applied to brass by this same method in the manufacture of cheap jewelry.

Coatings obtained by simple immersion are of little practical importance, however, due to the fact that the coatings at best are either exceedingly thin or are laid down in a porous and non-adherent condition. It is practically impossible to secure an adherent durable coating of copper on iron by this method. In fact, it is a general purpose of the electroplater to avoid solutions which will produce deposits by simple immersion without the aid of the electric current.

PRINCIPLES OF ELECTROPLATING PROCESS

Electroplating Cell. The electroplating cell consists usually of a tank or containing vessel for holding a suitable solution of the metal to be deposited. Metal bars from which the anodes are suspended are placed above the tank. These are connected to the positive lead of the dynamo or other source of current, while the bars from which the cathodes are suspended are connected to the negative lead from the dynamo.

It is customary to place an adjustable resistance or rheostat in series with each tank, so that the amount of current flowing through the tank can be adjusted in accordance with the amount of cathode surface. It is highly desirable, though by no means common prac-

tice, also to include an ammeter in series with each tank for measuring the current flow.

Current Supply. The current supply for plating may be derived from primary batteries, from storage batteries, or from a low voltage dynamo. The earlier art of electroplating was dependent almost entirely upon primary batteries, but the greatest advance in the art came with the introduction of the electric dynamo, whereby the cost of electrical energy was enormously reduced. For small scale and experimental work, a battery source may be most convenient; but for technical work, one of the highly efficient types of plating dynamos must be employed.

The voltage at which the dynamo must run is from three volts

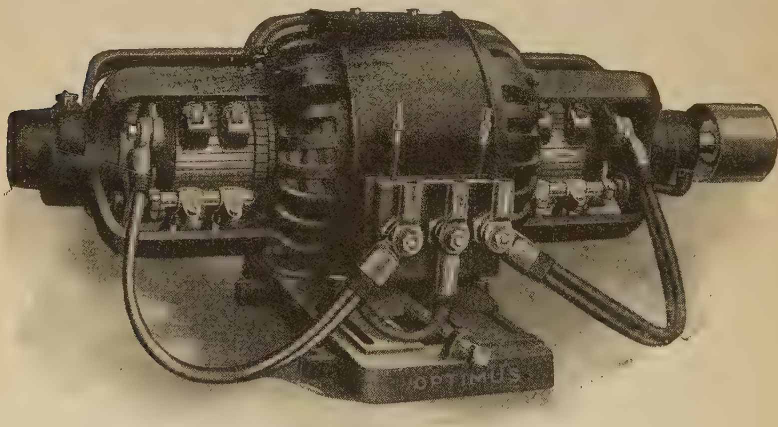


Fig. 2. Plating Dynamo with Double Commutator
Courtesy of Munning-Loeb Company

to six volts and sometimes even higher, dependent upon the general nature of the work to be done.

The low voltage plating dynamo is in general similar to the direct-current dynamo used for lighting and power purposes and differs in detail mainly in having a very large brush and commutator surface for carrying away, with as little heat as is possible, the large volume of current which is generated.

To give a large commutator and brush bearing surface, plating dynamos are frequently constructed with two commutators. Fig. 2 illustrates a modern type of plating dynamo. The leads running from the dynamo to the various tanks are usually of a very heavy

copper wire or bar suitable for carrying a large volume of current without heating and to produce a minimum drop in voltage.

Fig. 3 shows the method of connecting a number of plating tanks fed from one dynamo.

Anodes. The anodes which are usually employed are of the soluble type and consist of the metal which it is desired to plate. In some rare cases an insoluble anode may be employed but this always involves a progressive change in the composition of the solution and interferes with simplicity of operation.

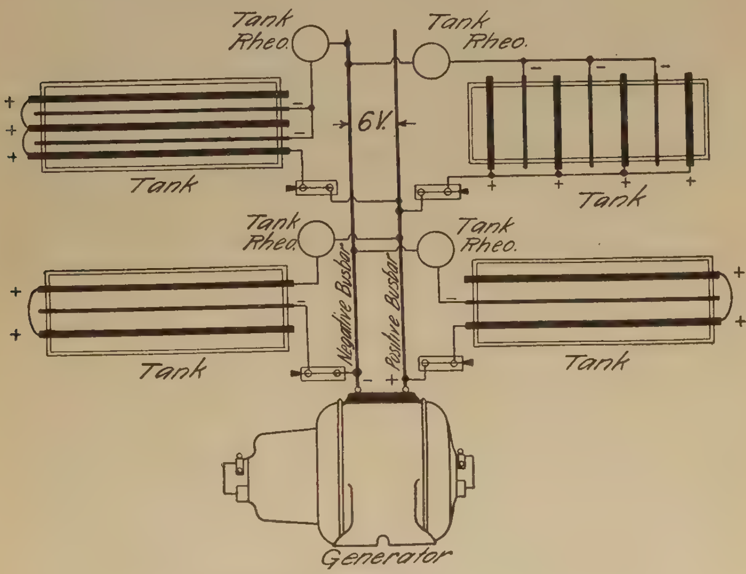


Fig. 3. Wiring Diagram for Tank Connections with Two-Wire Generator
Courtesy of Munning-Loeb Company

Factors in Successful Operation. *In General.* As to the general methods of operation, the electroplating process is simple, the metal being laid down by the action of the electric current, the thickness being dependent upon the amount of current and the length of time that the current flows. The process of electroplating is, however, beset with innumerable difficulties which the plater must know how to avoid. Much of the necessary information may be found in the various textbooks, but the successful practical plater is dependent largely upon the knowledge gained through extensive experience.

Quality of Deposit. The success of electroplating depends primarily upon the physical quality of the metal deposited. While in electrolytic refining coherence and density are not of greatest

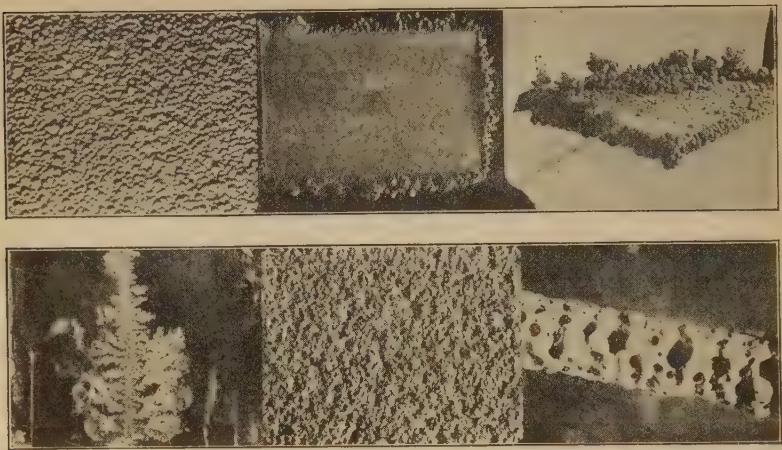


Fig. 4. Some Undesirable Forms of Electrolytic Deposits. Reading from Left to Right, Top: Nickel, Copper, and Iron. Bottom: Gas Bubbles in Heavy Nickel Deposit, Antimony, and Zinc
Courtesy of Metal Industry

importance, density, coherence, and adherence are absolutely essential for protective and ornamental coatings. In general, there is a tendency for electrodeposits to become rough, especially after attaining some thickness. It is possible to secure metal deposits which are fern-like or tree-like or, in fact, imitative of almost all forms of vegetation, and to suppress these undesirable forms and to secure a dense smooth deposit constitutes much of the work of the electroplater. He finds he can regulate the quality of the deposit by various methods, such as the density of the solution, the composition of the solution, the current density, the temperature, the impurities, and various other factors.

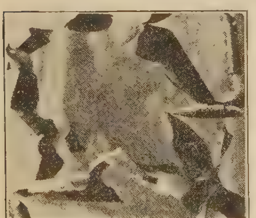


Fig. 5. Curling of Nickel Deposit
Courtesy of Metal Industry

Figs. 4 and 5 illustrate some of the forms which deposited metals may assume unless suitable precautions are observed.

Each metal has inherent qualities or tendencies as regards deposition. For example, nickel and iron tend to deposit in a fine-

grained dense state; copper is markedly crystalline; lead, tin, and silver tend to come down in a loose spongy or leaf-like formation; while platinum almost always deposits as an amorphous powder. It has taken about a century to develop the electroplating art to its present state in which practical working solutions are found for almost all of the metals. There is abundant opportunity, however, for further discovery of new electrolytes to overcome some of the present difficulties.

Addition Agents. A notable recent progressive step consists in the use of glucose or gelatin, or certain other inorganic materials, which, added to the ordinary plating solution, produce profound changes in the quality of the deposit.

Polishing. It is invariably desired that the resultant surface shall be smooth and polished. To secure the polish it is almost always necessary to subject the article to a buffing or burnishing operation. By the use of plating baskets and by the use of certain solutions, however, bright nickel and other deposits may now be secured.

The electroplater must know not only how to make up his original solutions from commercial materials, but even more important is his knowledge of how to maintain his solutions in constant working condition. If the anode metal does not go into solution in an amount exactly equal to that plated out at the cathode, the electrolyte will become depleted in metal and this must be supplied by dissolving up suitable materials. Careful attention is necessary to maintain a certain degree of acidity or alkalinity, as the case may be.

Influence of Current Density. The factor which the plater has chiefly under his control is the current density. It is usually desired that the metal shall be deposited as rapidly as possible, so that the output of a given tank shall be a maximum. There is a limit, however, beyond which the amount of current cannot be increased, and that is determined by the influence of the current density upon the quality of the deposit.

Each metal plating solution has a certain current density, usually expressed in number of amperes per square foot of cathode surface, beyond which the current cannot go. In nickel plating this is usually from five to ten amperes per square foot. In copper plating with a sulphate solution the current density may go far beyond this

figure. In general, a current density under ten amperes per square foot is employed.

If the safe current density is exceeded, it produces a discolored deposit usually termed a *burned deposit,* this term being employed on account of the resemblance of the coating to an actual heating effect.

Adherence. The adherence of a metal deposit depends on characteristics of the metals involved as well as upon the care in doing the work. If a metal having a high coefficient of expansion is deposited upon one having a low coefficient, there will be a subsequent tendency for the coating to flake or peel off. This is a factor which is, of course, beyond the control of the plater; but a much more important factor which is entirely within his control is the method of preparing the surface which is to receive the plating. If this is properly done, the deposited metal may actually alloy with the metal to be coated; while if it is not properly done, the adherence will be less perfect.

The primary requisite for a metal to receive a deposit is cleanliness. Not only must the surface be freed from ordinary dirt, grease, rust, paint, or the like, but it must be chemically free from oxides or other tarnishing films, some of which are so thin as to be invisible. If a cleaned article is brought into contact with the hands, a contamination of the surface may be produced which will make a subsequent coating non-adherent. This illustrates the extreme care which must be employed. Oils and grease are removed by the use of a hot alkaline solution. Acid solutions and pickles are employed for the removal of oxides. Each metal has its own particular acid pickle which yields the characteristic and best results, but these details need not be considered here.

Principal Items of Expense. Grinding and polishing constitute the most costly part of the electroplating industry. It is a purely mechanical operation, by which abrasives or polishing materials are used either to remove adhering impurities from a surface or to give a surface the necessary smoothness. It is almost invariably true that during electroplating the surface becomes rougher instead of smoother and irregularities become accentuated rather than covered up. For this reason if a resultant smooth surface is desired, as smooth a surface as possible should be started with. Grinding and polishing before plating are, therefore, fully as important as the polishing and burnishing after plating.

The most important items of expense incident to electroplating are labor and materials. Labor is used mostly in the mechanical operations in preparing the surfaces or finishing the surfaces and in suspending the work in the tanks as well as in removing and rinsing. Where very small articles are to be handled, the labor and expense of stringing on wires would be prohibitive and for this reason there have been developed what are known as plating barrels or drums, by which a receptacle full of the small articles is rotated in a plating solution and the electrodeposit is formed while the articles are in a tumbling motion.

Fig. 6 illustrates a modern type of rotary plater in which nails

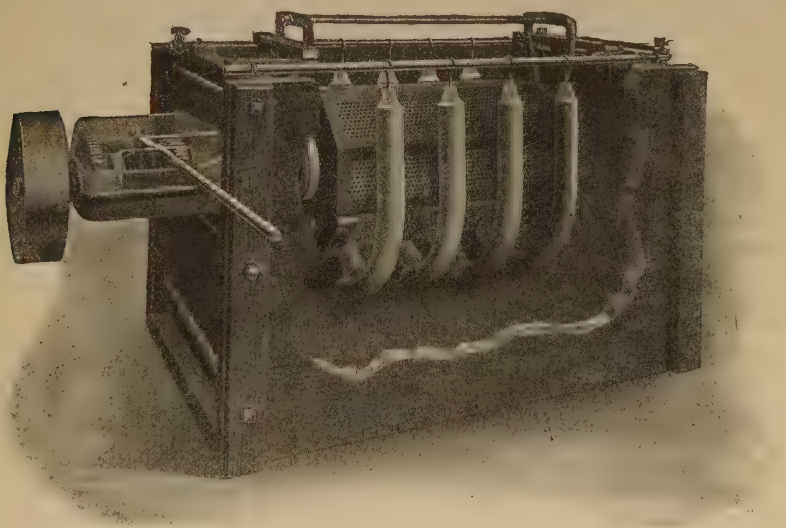


Fig. 6. Modern Rotary Plating Machine
Courtesy of Hanson and Van Winkle Company

or other small articles are plated without necessitating the stringing operation where each piece is handled separately.

WORKING SOLUTIONS FOR PRINCIPAL METALS

The following paragraphs give the essential details and satisfactory working solution for the deposition of each of the more important metals.

Copper. Copper is among the metals which are most easily deposited. A large number of different solutions are employed, but the action of the two typical ones will be described.

(1) *Acid Copper Solution.* The so-called acid copper bath may be made up according to the following formula:

Copper sulphate crystals (blue stone) ($CuSO_4+5H_2O$)	2 pounds
Sulphuric acid (H_2SO_4)	$\frac{1}{2}$ to 1 pound
Water	1 gallon

Copper anodes are used with this solution, and the electrolyte being highly conductive and the anode metal going into solution readily, a low voltage is required, usually somewhere between one and two volts. This depends upon the current density employed and upon whether the anodes and cathodes are far apart or close together.

The current density is usually from 10 to 20 amperes per square foot of cathode surface where the electrolyte is kept quiet. By rapidly circulating the electrolyte, however, much higher current densities may be employed while obtaining satisfactory deposits. With rapid circulation, current densities as high as 100 amperes and over may be employed.

This acid copper bath is used mainly for electrotyping and the deposition of copper in thick coatings. It cannot be employed satisfactorily for depositing directly on iron, because of the fact that iron throws the copper out by simple immersion and produces a loosely adhering deposit. When it is desired to copperplate on iron, the iron must be first given a preliminary coating from the so-called alkaline bath or the cyanide solution.

(2) *Alkaline Copper Solution.* Potassium cyanide is an exceedingly important chemical compound for electroplating use. It has the property of dissolving in water and then dissolving up various metal compounds, such as copper, gold, and silver, to produce excellent electrodeposits. The chief objection to its use is its deadly poisonous nature.

For preparing a cyanide copper bath, about $1\frac{1}{2}$ pounds of potassium cyanide is dissolved in a gallon of water. Three-fourths of this solution is warmed up and in it is dissolved copper carbonate to the saturation point. About 12 ounces of the carbonate will thus dissolve. After pouring off the clear liquor, the remaining one-fourth of the original cyanide solution is added and the electrolyte is ready for use.

Copper anodes are employed and an electromotive force of from 3 to 5 volts is necessary to get the results. A current density of

from 20 to 30 amperes per square foot may be used, although in operating under these conditions the amount of copper deposited is much less than is indicated by Faraday's law.

Nickel. The nickel bath in most general use is a saturated solution of the so-called double nickel salts. This consists of nickel ammonium sulphate $[(NH_4)_2.SO_4NiSO_4+6H_2O]$, twelve ounces of which will dissolve in one gallon of water. Nickel anodes, usually in the form of an impure cast nickel, are employed.

Some recent changes including the use of chlorides have resulted in improvements, but the old standard solution is in almost universal use.

In starting a batch of work, it is customary to employ a voltage of from 2 to 6 volts for a few minutes and then reduce to 2 or 3 volts, or even less. A current density of less than 10 amperes is all that can be economically employed. Too high a current density results in a black or burned deposit of nickel.

The above are simply illustrations of electroplating baths and are typical of those used for the deposition of zinc, silver, gold, etc.

PLATING NON-CONDUCTING BODIES

An interesting branch of the electroplating art has developed recently and has attracted marked attention on account of the novelty and beauty of the work which is being done. Fig. 7 shows how silver has been deposited upon glass and illustrates one of the numerous applications of a metal coating to a non-conductive material. Lace and other fabrics are being metallized; small animals, insects, flowers, leaves, and the like, can be coated electrolytically and thus be perpetuated in form and given the beauty of color through the range of those colors that lie under the control of the electroplater.

Rendering Surface Conductive. An essential step in the deposition of metals on non-conductive materials is first to render the surface conductive. This can be done in numerous ways; the best known being that illustrated by the practice of the electrotyper who takes a wax impression or mold from a form of type or metal design to be duplicated. This wax form is carefully dusted and brushed with a layer of high-grade conductive graphite, which, when applied to the mold, makes it appear like stove polish. This is the conduc-

tive surface which must constitute the starting point for the shell of copper which is subsequently to be deposited. For fabrics, flowers, leaves, or the like, the graphite will not adhere until first a layer of shellac or other sticky material is applied.

To avoid the use of graphite and the troublesome methods of applying, various chemical processes have been devised. A preliminary metal coating is obtained by dipping the article into a solution of a metal which is easily reducible. The wet surface is then treated with a reducing agent to throw out the metal, after which the plating can proceed by the ordinary chemical process. A solution of silver or platinum is suitable; phosphorus, pyrogallic acid, and various other reducing agents may be employed.

Fig. 7. Silver Deposit on Glass
Courtesy of Metal Industry

Plating on Glass. For plating on glass where the demand is for ornamental effect as well as a strongly adherent deposit, the glass may be rendered conductive by applying a metal paint, such as finely ground silver in turpentine, and then heating in a reducing atmosphere, under which conditions the silver will actually fuse to the glass. After cooling down, the glassware is wired in the ordinary way and put into the plating tank where the metal is deposited to the desired thickness.

DECOMPOSITION OF SALT SOLUTIONS

SODIUM CHLORIDE

Salt, NaCl, is a low priced and abundant material, which upon electrolytic decomposition may produce a number of valuable products for which there is a ready market. The apparent profits have attracted numberless inventors and, out of a large number of cells and processes which have been patented, a few have attained notable industrial success.

Decomposition of Solution. As explained on pages 41 to 44, the simplest and most direct way of decomposing salt is by the

fusion process, electrolysis yielding sodium and chlorine. But the great difficulties have confined most of the electrolytic work to the decomposition of aqueous solutions of salt.

Illustrative Experiment. A simple experiment, easily performed, will illustrate one practical application of sodium chloride electrolysis. A solution of salt in water, about five to ten parts to one hundred of water, is placed in a glass or other non-conducting vessel, Fig. 8. Two graphite electrodes are inserted and a direct current is caused to flow for an hour, at a current density of from ten to twenty amperes per square foot of anode surface. After the solution has then been electrolyzed, it has remarkable disinfecting

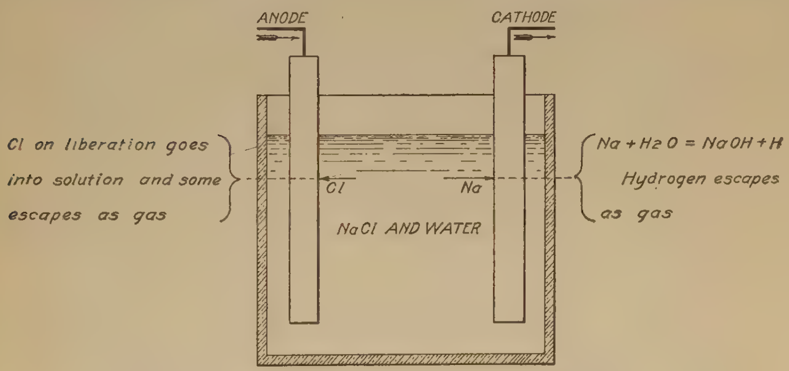


Fig. 8. Section of Electrolytic Cell Showing Decomposition of Sodium Chloride

and bleaching properties. A piece of colored cloth may be whitened, and one quart of the solution may sterilize a hundred thousand quarts of contaminated drinking water. Offensive odors may be quickly destroyed by the remarkable oxidizing power of this liquid.

As a result of these properties, this electrolytic cell has a field of usefulness in laundries; in textile mills; for purification of city water supplies; for disinfecting public swimming tanks; for treatment of sewage, for hospital use, and for many other purposes. A notable achievement has been the purification of an island in New York harbor which had been for years a dumping place for garbage, and which had become a public nuisance from the odors evolved. The purification was effected by electrolyzing sea water in wood tubs, using platinum anodes, and then pumping this solution on the land.

On account of the simplicity and effectiveness of the process, much attention has been drawn to it, and it naturally follows that extravagant and unwarranted claims have been made for it.

The oxidizing power of the electrolyzed salt solution is dependent upon the presence of sodium hypochlorite, NaOCl. This is similar in composition and chemical action to so-called chloride of lime or bleaching powder, which is calcium hypochlorite, $Ca(OCl)_2$.

Action in Cell. A study of the chemical changes which take place in this type of electrolytic cell, shows how sodium hypochlorite and various other substances may be produced.

$$Na+H_2O=NaOH+H \qquad (1)$$

$$2NaOH+2Cl=NaOCl+NaCl+H_2O \qquad (2)$$

or

$$6NaOH+6Cl=NaClO_3+5NaCl+3H_2O \qquad (3)$$

While there are numerous reactions which take place, the simplest and most important are those set forth in equations (1), (2), and (3).

The primary action of the electric current is to draw the chlorine ions toward the anode, and the sodium ions toward the cathode where they are liberated in an amount to agree with Faraday's law. The sodium cannot exist in the free state in contact with water, hence the reaction (1) takes place by which hydrogen is liberated as a gas, and a solution of sodium hydrate or caustic soda is formed. This is very soluble and diffuses throughout the electrolyte.

The chlorine which is liberated at the anode is soluble to some extent in the electrolyte, and it is only when liberated rapidly that some of it escapes as a gas into the atmosphere. There is, however, a strong affinity between chloride and sodium hydrate, and a chemical action shown by equation (2) takes place; that is, some sodium hypochlorite, NaOCl, is formed, together with an equivalent amount of salt and water.

If there is an excess of sodium hydrate, and the temperature is raised, the reaction becomes that shown in equation (3) where sodium chlorate, $NaClO_3$, is formed, together with salt and water.

The conditions can be regulated so as to favor either one of the reactions. That is, either hypochlorite or chlorate can be produced at the will of the operator, by variation of temperature, density of solution, and duration of electrolysis. Both of these materials have

strong oxidizing power and both have important technical applications.

It is evident that the decomposition of potassium chloride, KCl, may be effected in the same manner as the sodium chloride, and by its decomposition practically all of the potassium chlorate of commerce is now produced. This is a material used extensively in the manufacture of matches, explosives, and for other purposes where a strong oxidizing agent is needed.

MANUFACTURE OF HYPOCHLORITES

Chemical Action. As indicated above, the production of sodium hypochlorite takes place in accordance with the equation

$$2NaOH+2Cl=NaOCl+NaCl+H_2O$$

As the process continues there is a steadily increasing amount of sodium hypochlorite in the solution and, like the salt, it may in turn be decomposed by the current. When this occurs oxygen is liberated at the anode. Therefore it is possible to attain only a certain strength of solution before the hypochlorite is decomposed as rapidly as formed, and for the sake of economy of energy the concentration of hypochlorite is not usually carried much beyond ten grams of active chlorine per liter of solution. In using this solution for bleaching and disinfecting purposes there is a considerable consumption of undecomposed salt which is necessarily lost, and which adds to the cost of the process unless a very cheap source of salt, such as sea water, is employed. The important items of cost in sodium hypochlorite production are the following: salt, which is decomposed together with that which accompanies the hypochlorite solution; electrical energy; and anode renewal. Since oxygen is liberated at the anode, and since carbon and graphite corrode under such conditions, the anode loss may be considerable. The cost of electrolytic hypochlorite is usually greater than that at which an equivalent amount of bleaching powder can be purchased. Nevertheless on account of convenience, cleanliness, and greater effectiveness of sodium hypochlorite over calcium hypochlorite, this type of cell has extensive use.

Commercial Electrolyzers. Among the types of commercial electrolyzers for hypochlorite is the one illustrated in Fig. 9. This shows a supply tank for dilute salt solution, feeding in a steady

stream into the stoneware trough or electrolyzer. The overflow from this tank carries the hypochlorite solution into the larger rectangular storage tank below.

Since a pressure of about 5 volts is all that is needed between the anode and cathode, if current be taken from an ordinary lighting or power circuit, usually carrying a pressure of 110 volts, a rheostat

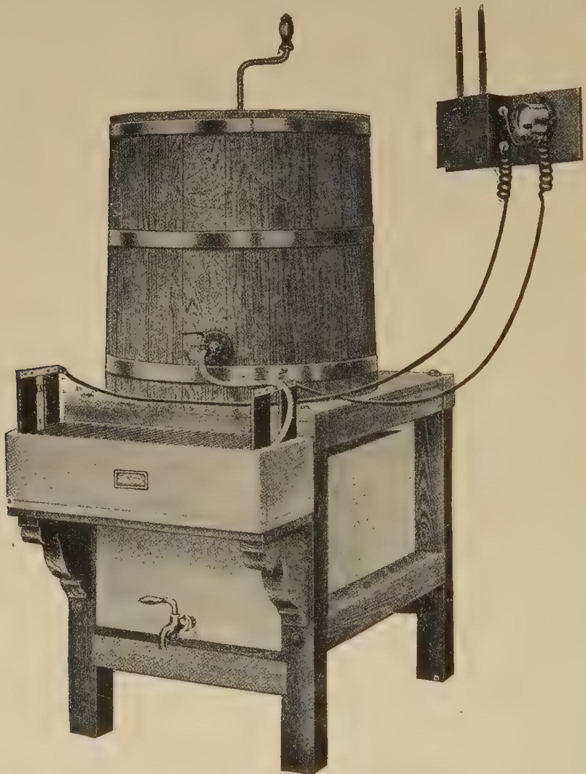


Fig. 9. Chlorinator, or Electrolyzer, for The Decomposition of Salt
Courtesy of the Valhalla Company

to reduce the pressure at the cell terminals to 5 volts will be necessary. Since this is exceedingly wasteful of electric energy, it is avoided by placing a suitable number of cells in series so that little or no rheostat regulation is necessary. This is accomplished in the apparatus illustrated by placing a number of partitions of graphite plates spaced evenly along the trough and separated by insulating cleats. The end plates are connected to the high voltage source of current.

This construction is illustrated diagrammatically in Fig. 10. Fourteen compartments are shown, divided by graphite plates. Each compartment acts as an electrolytic cell, the electric current flowing in at the left end plate, and the left-hand side of the next plate acts as the corresponding cathode. The right-hand side of this same plate serves as the anode for the next compartment, and so on. This construction serves as a simple method of connecting cells in series without using a containing vessel for each pair of electrodes.

The salt solution flows downward between plates *1* and *2*, under plate *2* which is spaced a short distance from the bottom, upward between plates *2* and *3*, over plate *3* and then downward, and so on through the electrolyzer. The rate of flow of the solution

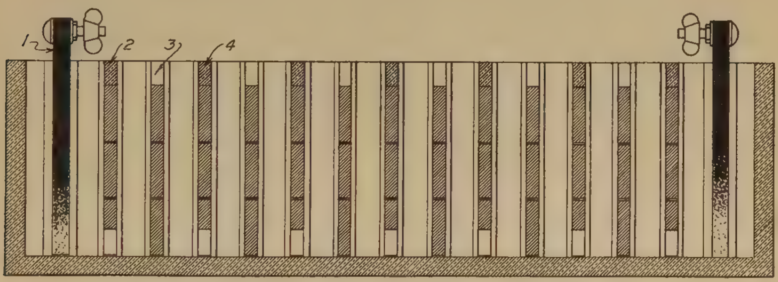


Fig. 10. Section of an Electrolyzer for Salt Solutions

is adjusted so that by the time it has passed through the last compartment it has been electrolyzed to the desired strength.

MANUFACTURE OF CHLORINE AND CAUSTIC SODA

A process of far greater industrial importance than the production of sodium hypochlorite is the electrolytic decomposition of salt solutions for the manufacture of chlorine and caustic soda. The chlorine which is liberated is absorbed by lime in the manufacture of bleaching powder, or it may be taken up by lime solution to form a hypochlorite bleach liquor.

Practically all of the bleaching powder now on the market is an electrochemical product. Paper mills and other larger users of bleaching powder have installed, or are installing, electrochemical plants for this purpose. Caustic soda, which may be considered a by-product of this industry, is in great commercial demand and

electrolytic caustic has largely replaced the products of the old methods.

Difficulties. In order that the electrolytic cell may deliver chlorine and caustic, it is evident that the construction and operation must be such as to prevent these materials coming together within the cell. Otherwise there would be formed sodium hypochlorite, which is decidedly detrimental; in fact the most effective test of the value of the electrolytic cell is the freedom from hypochlorite within the cell.

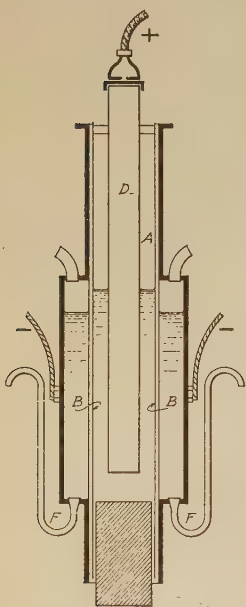


Fig. 11. Townsend Diaphragm Cell

Since the cathode product is extremely soluble in the electrolyte and the chlorine liberated at the anode also has considerable solubility, the problem of keeping these products separate is more difficult than is the separation of oxygen and hydrogen in the electrolytic decomposition of water. Several successful methods of effecting this have been devised, the principal ones being the use of some kind of a *diaphragm*, and the use of *mercury* as the cathode material.

Methods. *Diaphragm Cells.* As illustrating one of the several types of successful diaphragm cells, the Townsend cell may be referred to. This is employed in a large plant located at Niagara Falls.

The cell construction is shown diagrammatically in Fig. 11. The central compartment *A* contains the graphite anodes *D*. The anode channel is made up of a U-shaped framework of cement construction, the sides being closed by a sheet asbestos diaphragm *B* of special construction. On the outside of the diaphragm *B*, perforated iron girds are bolted tightly to the framework. On the outside of the cathode sheets are channels for the collection of the caustic soda. The particularly novel feature of this cell is that the two outer channels are filled with kerosene oil. The caustic soda solution which is formed at the cathode trickles through the diaphragm and sinks through this layer of oil and is drawn off through outlets *F*. This oil together with the diaphragm is intended

to secure the complete removal of the caustic from the anode liquor. The brine solution to be decomposed is introduced into the anode chamber and the rate at which the solution flows through the oil is determined by the height of the liquid in this compartment with respect to the height of the oil column in the outer compartments.

The removal of the alkali is so effective that very high current densities can be used and still maintain high current efficiency. These cells can be constructed to use 2500 amperes each. The operation of the cell shows a current efficiency of from 90 to 95 per cent, operating at a pressure of from $4\frac{1}{2}$ to 5 volts per cell. The caustic which is drawn off from the cathode channels is a 15 per cent solution with an equal amount of undecomposed salt. The distinguishing feature and greatest limitation of all types of diaphragm cells are that the cathode solution which is drawn off consists of a mixture of both salt and caustic. A separation of these materials is necessary to put the caustic into a marketable condition and to prevent unnecessary waste of salt. This is accomplished by evaporation, the salt crystallizing out as the solution is concentrated.

Mercury Cells. Mercury has a remarkable property when used as the cathode in a salt solution, which is of great interest from a scientific standpoint and of great value from an industrial standpoint. When sodium is liberated on most cathode surfaces, it immediately unites with the water of an electrolyte to form caustic soda and liberate hydrogen. If, however, the cathode is mercury, the mercury absorbs the sodium before it has time to react with the electrolyte. It takes it in the form of an alloy or amalgam up to several per cent of its own weight. The completeness with which the sodium is taken up by the mercury depends somewhat upon the temperature, but more especially upon the purity of the mercury.

If this lead mercury amalgam be removed from the cell and placed in another compartment, it may be made to give up its sodium by using the amalgam as the anode. The sodium then goes into solution and forms sodium hydrate and liberates hydrogen upon the cathode. A simple method for making the amalgam act as an anode is to bring in metallic contact with it an electronegative material such as carbon or graphite.

The Castner cell is one of the oldest and most successful of the mercury type. Its construction is shown diagrammatically in Fig. 12,

where it is indicated that the cell is divided into three compartments by two vertical partitions extending almost to the bottom of the cell, but not making a tight joint therewith. *A* and *C* constitute the anode compartments in which graphite anodes are employed. A layer of mercury rests on the bottom of the cell, making a seal beneath the two vertical partitions. The current is conducted away from the cell through the iron cathode in channel *B*. The current to flow through the cell must pass from the anode through the brine solution, thence to the mercury, and from the mercury through the caustic solution in compartment *B*, then to the iron cathode, and thence from the cell. The sodium mercury amalgam is formed in the anode compartments and this amalgam is transferred

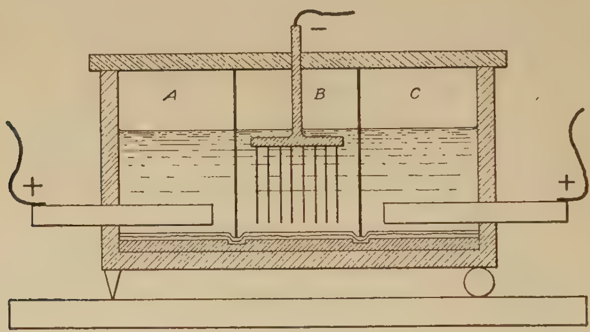


Fig. 12. Castner Mercury Cell

to the central compartment by a slow rocking motion which is given to the cell. The amalgam, therefore, surges back and forth, and while passing through the central compartment acts as anodic surface.

The actual operation of this cell introduces various complications which need not be described here, but the cell has been very successful from a commercial standpoint in producing chlorine and caustic soda of high purity. An obvious limitation on the construction is the necessity of rocking the entire cell and this feature has been avoided in the construction of another successful type of mercury cell known as the Whiting cell.

The cell body is a stationary, massive construction of concrete in which the mercury rests in thin layers in the anode compartments.

There are a number of divisions to the anode compartments and the mercury from each of these devices is discharged intermittently and in rotation into the oxidizing chamber where it comes in contact with graphite plates against which it gives up its sodium to the caustic soda solution. After the sodium has been extracted, the purified mercury is elevated by a stoneware wheel so that it flows back again into the anode compartments. The construction of this cell is illustrated in Fig. 13, and Fig. 14 shows a large sized working plant of this construction. A cell 6 feet square takes 1400 amperes at a voltage of about 4 volts. A pure caustic is produced and, on

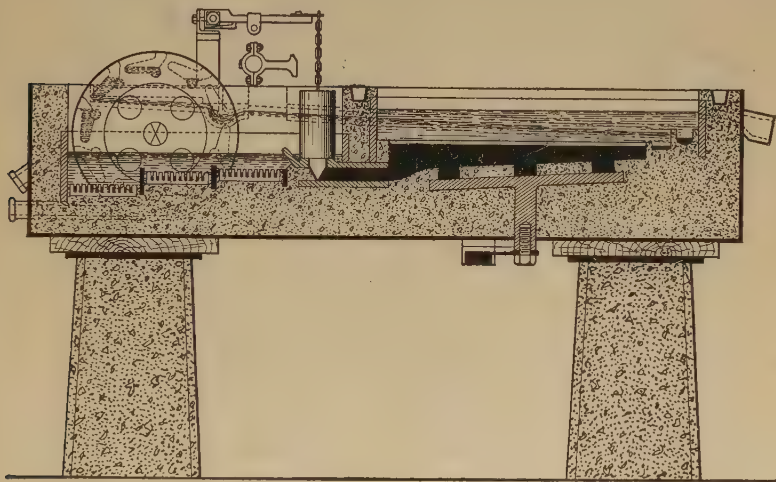


Fig. 13. Cross Section of Whiting's Electrolytic Cell

account of the high current efficiency, there is little hypochlorite production and, therefore, small anode loss.

Relative Advantage of Mercury and Diaphragm Types. In view of the rapidly extending use of cells for decomposing salt, there is much discussion as to the relative merits of the mercury and diaphragm types of cells. The most important advantage of the former is its ability to produce a pure caustic soda solution, thus avoiding the expensive plant and costly operation of removing the salt from the caustic. On the other hand, the diaphragm process has the apparent advantage of cheaper cell construction, since the use of the costly mercury is avoided. Many other factors of lesser

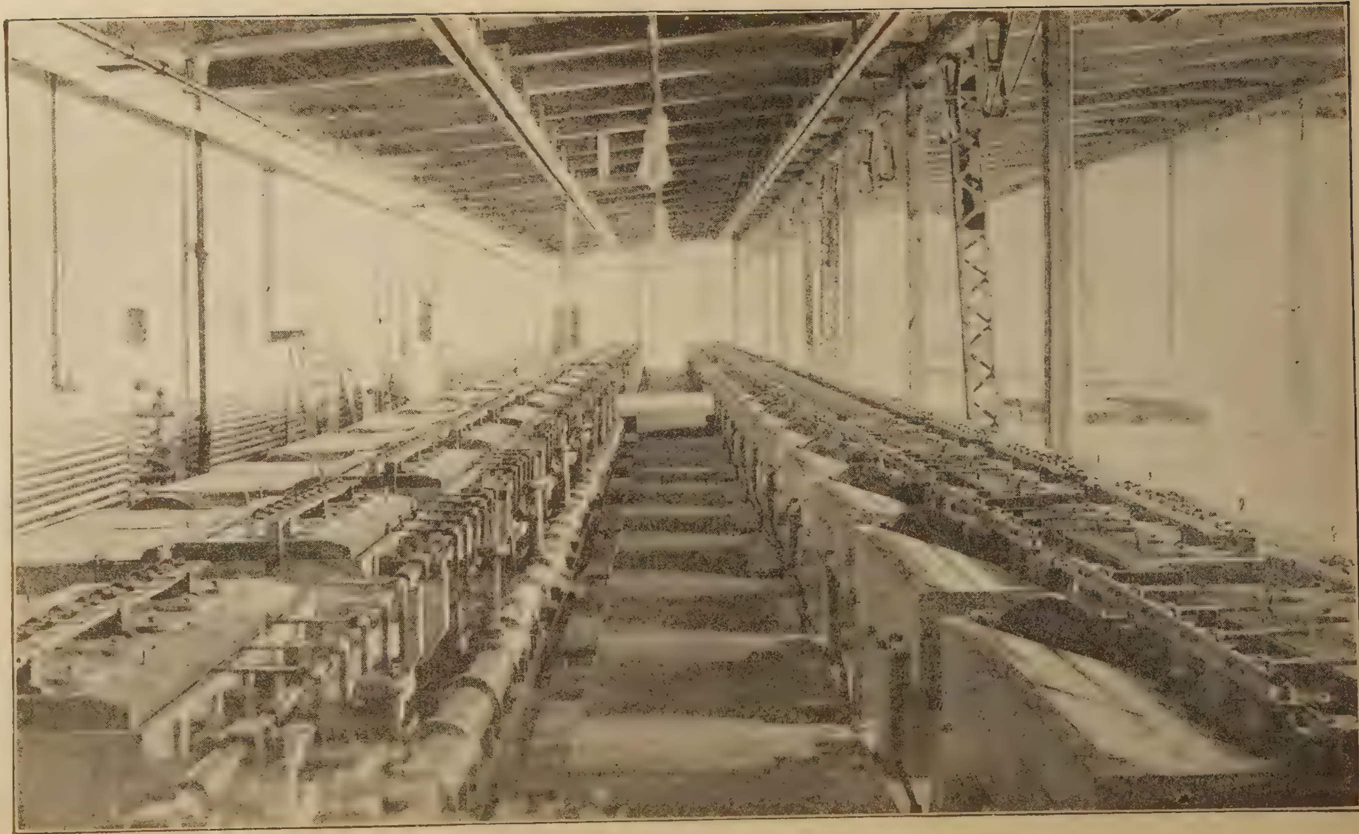


Fig. 14. An Installation of Whiting Cells in Operation

importance must be taken into account in considering the relative merits of the two types of cells, including the depreciation, anode renewal, cost of salt, cost of power, labor, etc. Whether or not one cell has the advantage of the other depends to some extent upon local conditions.

ELECTROLYTIC HYDROGEN AND OXYGEN

Uses of Hydrogen and Oxygen. Hydrogen and oxygen have extensive industrial applications. In addition to their many uses in chemical manufacture, these two gases are coming into extensive employment for oxy-hydrogen welding, and for other metallurgical operations. Oxygen is also used for similar purposes in connection with acetylene, and other hydrocarbon gases. Hydrogen is an excellent chemical reducing agent, and one of its large applications is for aeronautic use.

Hydrogen is given off at the cathode as a by-product in the decomposition of salt solutions and in various other electrolytic processes, and is usually regarded as a waste product. Oxygen is of greater value. It is produced to some extent by the liquefaction of air and its subsequent distillation. In this case it is mixed with a small amount of nitrogen but enough to prevent its most efficient use in attaining high temperatures in combustion operations. The pure gas can be made most economically by the electrolytic method, and the simultaneous production of both oxygen and hydrogen constitutes a profitable electrolytic industry.

Cells for Decomposing Water. Electrolytic cells of various types have been developed. They all employ either a sulphuric acid, or a sodium or potassium hydrate solution as electrolyte. Where the acid solution is used, lead is the material used in the cell construction; while with the alkaline electrolyte, iron is employed. This choice of materials is made because of the insolubility of lead and of iron in the respective solutions. It is obvious that insoluble anodes must be employed to allow the escape of oxygen.

Separation of Gases. An important point to be attained in water decomposition is that the anode and cathode products be kept as completely separated as possible. The bubbles of hydrogen coming off the cathode surface must not mingle with the oxygen bubbles from the neighboring anode surface. Otherwise impurity

of products results and, what is of greater importance, a liability of explosion is produced. Numerous fatalities have resulted through inadequate precaution in this respect.

The electrodes must be placed as near together as practicable to reduce the resistance and the power consumption to an economical figure.

A 20 to 30 per cent sulphuric acid solution has a better conductivity than a 10 to 25 per cent alkali solution. On the other hand,

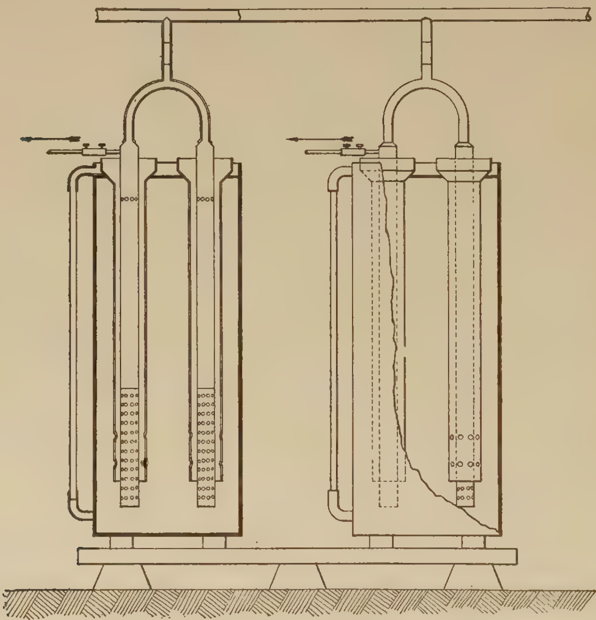


Fig. 15. Sections of Schoop Electrolyzer

it takes a somewhat higher electromotive force to liberate oxygen and hydrogen from the former solution, so that electrolyzers using the caustic soda or caustic potash have a slightly lower energy consumption than have those using the acid. The current efficiency approaches close to 100 per cent; that is, the oxygen and hydrogen are liberated in almost exact accord with Faraday's laws. This is essential to produce gases of the highest purity—about 99 per cent pure. Since the acid or alkaline is added to the electrolyte to give the conductivity to it and water alone is decomposed, it is necessary to add distilled water from time to time to replace that electrolyzed.

Types of Cells. Among the various types of electrolyzers employed are the following:

Schoop. The Schoop system uses sulphuric acid and cylindrical lead-lined vats containing a number of vertical electrodes. These are in the form of long tubes filled with fine lead wire to increase the

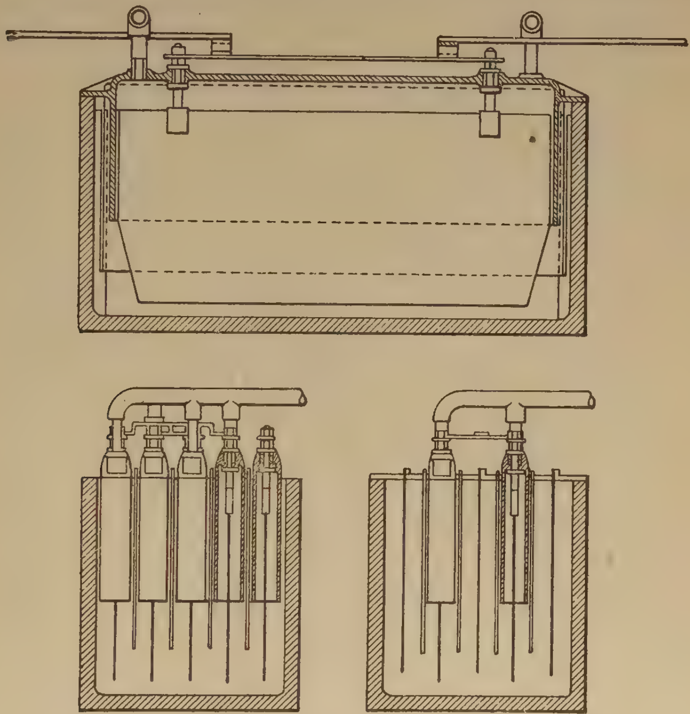


Fig. 16. Sections of Schuckert Electrolyzer

active electrode surface, each electrode being surrounded by a cylindrical tube of non-conductive material open below and perforated toward the bottom to allow the flow of current. The gas generated inside of this tube passes upward, where it is collected. This apparatus is illustrated in Fig. 15.

Schmidt. The Schmidt electrolyzer uses an alkaline electrolyte and the construction resembles a filter press. The electrodes are iron plates corrugated and are separated by diaphragms of asbestos with rubber packing around the edges. The purpose of this diaphragm is to keep separate the anode and cathode gases.

Schuckert. Another illustration of the alkaline type of cell is known as the Schuckert. In this an iron trough is divided into a number of compartments by vertical partitions of an insulating material extending from the top three-quarters of the way down the cell. These compartments contain alternately iron anodes and cathodes. Iron hoods suspended between the partitions carry off the gases. The construction of this cell is shown in Fig. 16.

A full sized plant equipped with International Oxygen Company

Fig. 17. Installation of an Oxygen-Hydrogen Plant
Courtesy of International Oxygen Company

cells is shown in operation in Fig. 17. For these cells a pressure of from $2\frac{1}{2}$ to 3 volts and a current of 600 amperes is required.

Plant Equipment. An essential part of any electrolytic plant is a high pressure pump which is used to compress the gases into tanks for storage, although when the gases are to be used where manufactured, large tanks such as are used in gas works may be sufficient. Precautions against explosions must be carefully observed. In operating the compressor oil is not permissible for cylinder lubrication on account of the possibility of the oil getting into the oxygen and forming an explosive mixture. Glycerine is commonly employed for

this purpose. Among other safeguards is the use of either an iron tube kept at a red heat or a tube filled with platinum sponge, or similar contact material. The gases from the electrolytic tanks will pass through such tubes, and whatever hydrogen there may be in the oxygen, or whatever oxygen there may be in the hydrogen, is consumed in producing water, and the purification is thus effected.

The gases when used for blow-torch purposes are passed through water-cooled funnels to prevent any possibility of the flame traveling backward into the tanks.

In view of the improvements being made and the high economy of the process, the electrolytic generation of oxygen and hydrogen promises to become an industry of great importance.

FUSED ELECTROLYTES

The majority of chemical compounds which are solid at ordinary temperatures become conductive when heated up to and beyond the melting points. The nature of this conductivity is usually electrolytic; that is, the molten materials are electrolytes which are capable of undergoing decomposition during the passage of a direct current. The conductivity of these materials is usually of about the same order as that of aqueous solutions.

The fact that we have molten electrolytes is of considerable technical importance, for upon it is based the recovery of various metals which would decompose water and, therefore, be unrecoverable by use of an aqueous solution. The aluminum industry is based upon the decomposition of a fused aluminum compound. The production of calcium, of sodium, and of magnesium is likewise dependent upon the decomposition of fused compounds of these respective metals.

MANUFACTURE OF SODIUM PRODUCTS

Fused Salt. The chemistry of the decomposition of melted salt is much simpler than is the chemistry of decomposition of aqueous solutions of salt. The electrolyte consists of only two elements: sodium and chlorine. Salt can be melted at a temperature of about 900° C. (a bright red heat). When placed in a suitable container and with an anode of carbon and graphite and a cathode of iron or other suitable metal, the sodium is liberated at the cathode and the

chlorine at the anode. These two elements being liberated have nothing with which to react, as in the case of aqueous solutions, and they will thus be recovered in the free state.

The simplicity of this process is, however, apparent rather than real when considering the various practical difficulties which are encountered. These difficulties depend upon the high temperature, under which condition the sodium vaporizes and has to be cooled by some suitable method. Such suitable method, however, has not been worked out technically. The chlorine which comes off at the anode being very hot is correspondingly active and the collection and cooling of this material presents difficulties. Also the construc-

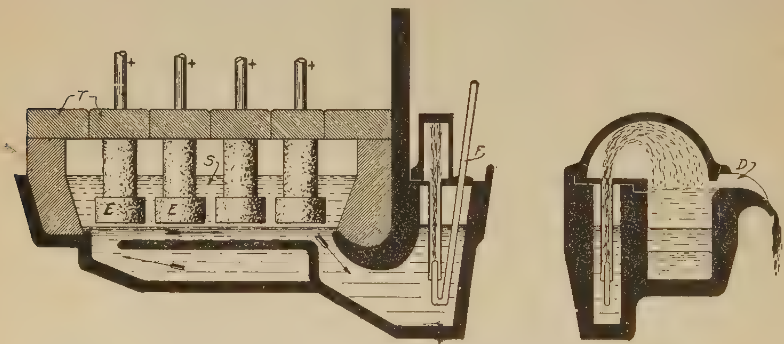


Fig. 18. Sections of Acker's Caustic Soda Furnace
Copied from The Electric Furnace, by Alfred Stansfield

tion of a containing vessel which will resist the attack of fused salt as well as of the liberated sodium and chlorine, is not a simple matter, and the practical difficulties have defeated many attempts to carry out this process.

Acker Process. Perhaps the most successful attempt has been the so-called Acker process, which was used for a number of years at Niagara Falls. In this process the fused NaCl was electrolyzed in a cast-iron cell of peculiar construction and lined with magnesia bricks. A cross section of this cell is illustrated in Fig. 18.

The cathode covering the bottom of the cell is fused lead above which rests a 6-inch layer of molten salt S and dipping into this are a number of graphite anodes E with terminals coming up through the tile roof of the cell T.

This process works upon the interesting principle that, when sodium is liberated upon molten lead, it alloys with the lead, forming

an amalgam similar to the amalgams of sodium and mercury of the mercury process. To prevent the amalgam becoming too rich in sodium, the sodium is continually extracted from the molten metal by blowing steam through it by pipe F, as indicated in the right portion of the diagram. The steam on coming in contact decomposes the sodium to form sodium hydrate, NaOH, and liberates hydrogen. The molten caustic soda thus produced flows out of the cell through at D. The reaction between the steam and the amalgam is violent and causes a vigorous circulation of the molten lead.

The chlorine which is liberated in the anode is drawn off from the anode chamber under a slightly reduced pressure by means of a fan. This causes some inflow of air through the crevices in the cover and the gaseous products thus drawn off consist of one volume of chlorine to about ten times the volume of air, the chlorine being then extracted from this mixture by means of lime to form the commercial bleaching powder.

These cells took about 800 amperes at a voltage of about 7 volts, the current efficiency being about 93 per cent.

The anodes were found to have a high durability unless a considerable amount of impurity was in the salt; the presence of sulphates, for example, causes anode corrosion.

The caustic soda produced from this cell is in a fused condition, which on solidifying furnishes a marketable product without the necessity of evaporation involved by the aqueous electrolytic methods.

The high temperature difficulties and the difficulties of cell construction have apparently made it impossible for the fused electrolytic cell to compete commercially with the aqueous methods of sodium chloride decomposition, although future improvements may reverse this condition.

Metallic Sodium. In the manufacture of metallic sodium the electrolytic methods have replaced the older chemical methods and the success has been dependent upon the use of a fused electrolyte which melts at a point much lower than that of salt. The process in most general use is the Castner process, which employs molten caustic soda, NaOH. This is contained in an iron vessel, Fig. 19. In this apparatus there is an extension below the cell for the cathode rod D and it becomes sealed by the solidifying of some of the sodium

hydrate at *G*. The cathode may consist of any one of several metals, iron being preferable. A cylindrical nickel anode *C* surrounds the cathode and between the electrodes is suspended a cylindrical screen of iron gauze. This prevents the sodium globules which are liberated on the cathode from floating over to the anode. The sodium which floats to the surface is ladled out periodically from *F* through the cover. For successful working, the temperature should be maintained by external heating as low as possible—not more than 20 per cent above the melting point of the material. The somewhat impure material commonly used has a melting point of about 300° C.

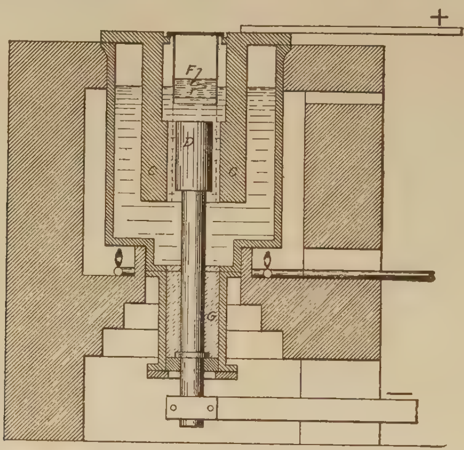


Fig. 19. Castner's Sodium Furnace
Copied from The Electric Furnace, by Alfred Stansfield

A single cell holds about 250 pounds of molten NaOH, takes a current of 1200 amperes at about 5 volts, and works at a current efficiency somewhat less than 50 per cent.

MANUFACTURE OF ALUMINUM

Aluminum is a metal which a half century ago was almost a chemical curiosity but which has now become one of the common and most useful metals in every day service. Although aluminum is one of the most abundant of the elements constituting the earth's crust, it has been locked up so tightly in combination with oxides, silicates, fluorides, and the like, that it has resisted until recently all efforts to isolate it in the metallic state. This has been finally accomplished in a practical way by electrolysis of fused aluminum compounds.

This element is found as an important constituent in most clays, but the known methods of extraction do not yet permit the use of such materials as an aluminum ore. Bauxite, which contains a high per cent of aluminum as hydrated oxide, is used almost exclusively in this industry, but to adapt it to the electric furnace requires, first, a chemical purification to remove such objectionable elements as iron, silicon, and titanium, after which process the material to be treated consists of a pure aluminum oxide, Al_2O_3.

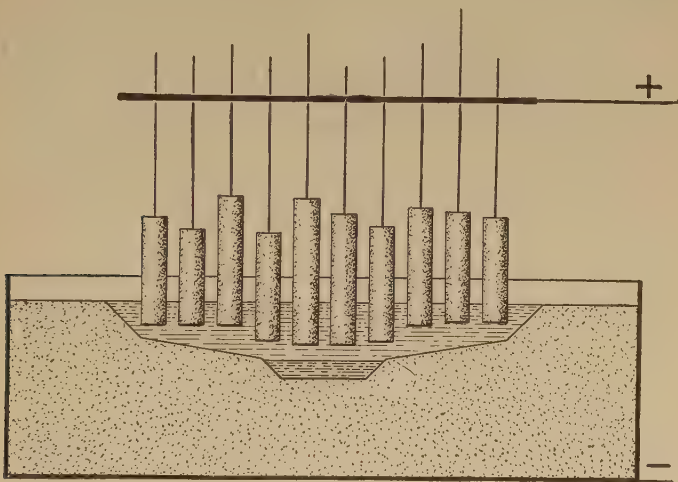


Fig. 20. Aluminum Furnace
Copied from The Electric Furnace, by Alfred Stansfield

The history of the aluminum process is interesting in that it records the almost simultaneous discovery of similar processes in America and in Europe. To Mr. Charles M. Hall is accorded the honor of working out the method commonly used in this country and by which the entire consumption of aluminum in America is supplied.

Hall Process. *Type of Cell.* The typical electrolytic cell, Fig. 20, may consist of an iron box about 6 feet long, 3 feet wide, and 3 feet deep, lined with a thick layer of conductive carbon. This layer prevents the fused material from coming in contact with an iron container and it also acts as the cathode terminal of the cell. The anode consists of a multiplicity of carbon rods 3 inches in diameter, suspended vertically in rows and numbering perhaps 40 to 50.

Solvent for Aluminum Oxide. The important discovery upon which this process is based was in finding a suitable solvent for the aluminum oxide. Such solvent was molten cryolite, being a combination of sodium and aluminum fluorides, represented by formula $3NaF.AlF_3$. Calcium fluoride, CaF_2, is also added on account of its influence on the fusibility. This molten material readily dissolves a certain amount of the aluminum oxide, constituting a true electrolyte which undergoes decomposition upon the passage of the current.

A layer of charcoal is placed on top of the molten bath to protect it from oxidation, and the dry aluminum oxide is fed through this layer to replace that decomposed.

Action of Current. A cell, such as described, takes about 10,000 amperes of current at a pressure of 5.5 volts or upward, depending upon the condition of the bath.

In this cell the current serves a double purpose of heating the bath and keeping it in the proper molten condition for electrolytic decomposition. The aluminum is deposited on the carbon bottom constituting the cathode. At the working temperature the metal is molten and having a greater specific gravity than the electrolyte stays on the bottom. After it has accumulated to a suitable amount, it is tapped off.

At the carbon anodes a corresponding amount of oxygen is liberated and, at the temperature necessary for operation, this oxygen unites with the anode carbon to form carbon monoxide, a gas which on rising upwards burns in contact with the air to CO_2. The consumption of carbon may thus amount to from .5 to .7 of a pound, although on account of the action of the air on the heated carbon anodes and the scrap anodes which are produced, the consumption may run up to about one pound for each pound of material. The current efficiency is reported as being from 70 to 80 per cent. The energy consumption is stated to be about 23,000 kilowatt hours per ton of metal, or stated in other terms, one electrical horsepower a year will produce about one-quarter of a ton of aluminum.

Electrolyte. The electrolyte consists in the main of a number of compounds, chiefly sodium fluoride, aluminum fluoride, and aluminum oxide. It is a well-known fact in electrolysis that that compound in the electrolyte which has the lowest decomposition

pressure will be the first one to be decomposed by the current. The following figures show why it is that the aluminum oxide undergoes decomposition rather than the sodium fluoride or the aluminum fluoride:

NaF —4.7 volts, decomposition pressure
AlF_3 —4.0 volts, decomposition pressure
Al_2O_3—2.8 volts, decomposition pressure

If during electrolysis there is an exhaustion of the aluminum oxide, the aluminum or the sodium fluorides may then be decomposed; this also happens to some extent if the current density is run too high.

The increasing demand for aluminum promises to make this industry of increasingly greater importance and this will be accentuated as the price is reduced. A scarcity of suitable ores is becoming felt and increased attention is being given to the extraction of kaolin and other cheaper and abundant materials.

ELECTRIC FURNACE

The use of electrical energy for the production of useful heat is becoming revolutionary not only in the field of metallurgy or technical chemistry where heat is utilized, but also in its effect upon the electric power industry. It is furnishing a load for power stations, or in other words a market for their product. Where heat from electrical energy is used for low temperature operations, such as cooking, drying, soldering, and the like, it is not generally classified as a branch of electrochemistry. When, however, high temperatures are attained, we pass into what is generally considered the field of electrochemistry. There is, however, no sharp line of demarcation as between low temperature and high temperature electric heating.

The device or structure used for transforming electrical into heat energy, where high temperatures are required, is called an electric furnace. The ability of the electric furnace to attain temperatures far beyond those hitherto available by other methods gave it a distinct field of usefulness in which it did not have to compete with existing furnaces. By the use of these temperatures many of nature's most closely guarded secrets have been revealed; a new chemistry of high temperatures has been evolved; new ideas as to the constitution of matter have been developed; new methods of

preparing known substances have been formulated; our stores of available materials have been enriched by the discovery of new compounds.

Possibilities at High Temperatures. *All Substances Melt.* In the high temperature produced in the electric furnace it has been shown that all substances can be melted. The oft encountered statement that lime, magnesia, molybdenum, tungsten, and the like, are infusible is therefore incorrect, for not only can all known substances be melted, but they can be volatilized as well. These facts are full of significance and suggestion to the investigator. They show not only that there are limitations upon the materials which he may use for furnace construction, introducing difficulties where the highest temperatures are to be developed, but that it is possible that in the melting and fusion of materials they may undergo such transformation of their physical nature as to endow them with qualities of great value. One of the most successful industrial uses of the electric furnace is the fusion of aluminum oxide in the form of bauxite, resulting in the production of that physical form of the material designated by the trade name "alundum". This is a duplication of Nature's process for producing corundum, but the artificial product has marked advantages over the natural material in purity, cheapness, strength, and toughness, which give it greater value for abrasive purposes.

The fusion of quartz has produced a valuable material for a new kind of glassware which is indestructible by rapid or extreme variations of temperature. Various refractory materials have their refractory qualities increased by melting and subsequent cooling. Experimental investigation in this direction has only begun, but the results already obtained point to many improvements which may be made in materials for furnace construction, materials resistant to chemical corrosion, and materials possessing high heat and electrical insulating properties. The volatilization of elements and compounds at high temperatures gives new methods for the purification and separation of materials, enabling the process of fractional distillation to be applied to all substances.

Behavior of Carbon. It has been shown that carbon is capable of conversion into its various forms, a fact industrially utilized with great advantage by the International Acheson Graphite Company

in making graphite and graphitized electrodes from the ordinary forms of coal and coke. Moissan has demonstrated the possibility of changing carbon into the diamond, and has reproduced, artificially, all the varieties of diamonds which Nature furnishes, alike in all respects save size.

All the oxides which had hitherto been regarded as irreducible have been reduced through the use of the electric furnace. Upon experiments which he has made, Borchers based the claim that carbon is capable of taking the oxygen from any known compound at temperatures within the range of the electric furnace. Similarly, other reducing agents may be made effective, and the decomposition can be produced even without any reducing agent whatever by utilizing the electrolytic action of the current. This has resulted in unlocking various of Nature's stores, making available for use such materials as aluminum, magnesium, calcium, sodium, potassium, chromium, silicon, and many others which previously could be obtained only with great difficulty if at all.

Carbides. Moissan's classic researches show us that a large number of elements unite with carbon to form carbides, many of which were not known before the day of the electric furnace. Based upon this fact, though resulting from the independent discovery of the American inventor, Willson, the calcium carbide industry has been developed, and today thousands of tons are being produced annually. The reaction of this carbide with water forms the hydrocarbon, acetylene, which, although now finding its chief use as an illuminant, is capable of being transformed into other hydrocarbons. Manganese carbide reacts with water to form hydrogen and methane; thorium carbide gives ethylene; and cerium and uranium carbides yield liquid and solid hydrocarbons as well as the gaseous ones. Although the hydrocarbons other than acetylene have not been produced commercially, scientifically it is possible to produce petroleum and other like compounds. Such discoveries as these point to the great and significant fact that the whole field of organic chemistry offers itself as an incentive in the exploitation of the electric furnace.

Another class of carbides, such as those of silicon, boron, chromium, molybdenum, tungsten, and titanium, are stable, not only resisting the attack of water but being extremely resistant to the

most active chemical agents. The first of these, silicon carbide, or carborundum, has found extensive application as an abrasive, and its use has led to the development of a new industry. Its extreme hardness, approaching that of the diamond, and the refractory nature of it and similar carbides, together with properties which may yet be discovered, point to the probability as well as the possibility that other carbides will have quite as extensive industrial application.

Related Compounds. Moissan and his contemporaries have shown that silicon, boron, and nitrogen, may be made to act like carbon in producing silicides, borides, and nitrides, each new compound having its own peculiar properties, and that the field may also be extended through the manufacture of the more complex compounds, such as the silico-borides, silico-carbides, boro-carbides, etc.

A contemplation of such possibilities is most bewildering, and to quote from an address by Professor Jos. W. Richards referring to electrometallurgical progress, "We are so overwhelmed by new things of possible use to science or industry, that we can at most investigate only a small fraction of them. It is a virgin continent of undeveloped possibilities."

ADVANTAGES OF ELECTRIC FURNACE

The electric furnace owes its place in the scientific and industrial world to certain characteristics which it possesses and to the advantages which it offers over other means of generating heat, the principal one being the high degree of temperature which is made available. An interesting comparison might be worked out showing that civilization progresses in a rate proportional to the utilization of heat energy in its highest degree of concentration. Each additional degree of temperature which can be produced and kept under control shows itself capable of new and useful purposes, and the electric furnace has added such an extension to the range of available temperatures that it has almost doubled that previously available.

Limitations. It simply requires the passage of the electric current through a conducting medium to produce heat, the intensity of which depends upon the amount of current which passes. Inasmuch as most substances retain their conductivity at high temperatures, the degree of intensity which is theoretically possible is unlim-

ited. Practically, however, limitations are placed upon it through the physical difficulties of keeping the conducting medium and the furnace walls in place. The temperature is limited by the fusing point of the material, while it retains its solid condition; when fusion commences, the difficulties of containing the melted material begin, and the temperature is limited by the point of vaporization.

When volatilization begins, the gaseous materials escape from the field of action, carrying away the heat, as rapidly as it is supplied to the furnace, in the form of latent heat of volatilization or energy stored up as potential chemical energy. It is true that the temperature of volatilization might be increased by subjection to high pressure, but this involves the construction of a container which can be made only of solid materials which will not fuse at the higher temperatures.

The electric arc maintained through a carbon vapor furnishes, perhaps, the highest temperature attainable, a temperature which is usually considered definitely fixed by the volatilization of carbon. On account of the limitations of our methods of measuring these high temperatures, the exact value to be assigned to the temperature of the electric arc cannot be stated, though the most satisfactory measurements give values ranging between 3600° and 4000° C. Whether or not this is the ultimate limit to be attained by electrical means is difficult to say. There is, of course, the possibility of exceeding it by maintaining the arc under a high atmospheric pressure, or by feeding electrical energy to the arc more rapidly than it can be dissipated by the volatilization of carbon, or, in other words, superheating the carbon vapor. Such speculation, however, is not necessary to show that the electric furnace has unbounded possibilities, since the range of temperatures below that of the ordinary arc offers an unlimited field for usefulness.

Comparison Between Electrical and Fuel Heating. While the attainment of high temperatures was the first achievement which called attention to the electric furnace and found many technical uses for it, the later developments have been in the direction of using electrical heating in competition with the various metallurgical processes where the combustion of fuel is employed. There are some who doubt the ability of the electric furnace to make inroads upon the fields occupied by other types of furnaces, and maintain heat energy from electricity to be entirely too costly, arguing as follows:

TABLE III

Relative Fuel Costs

Source of Heat	B. t. u. at Cost of One Cent
Coal at $2.50 per ton	112,000 B. t. u.
Natural gas at 20c per M	45,000 B. t. u.
Oil at 4c gallon	32,000 B. t. u.
Producer gas at 4c per M	37,500 B. t. u.
City illuminating gas at $1.00 per M	6,000 B. t. u.
Electrical energy at 10c per kw. hour	340 B. t. u.
Electrical energy at 1c per kw. hour	3,400 B. t. u.
Electrical energy at ¼c per kw. hour	13,600 B. t. u.

Cost of Heat from Fuels. A cheap source of heat energy is coal. On the assumption that one ton of a good grade of coal costs $2.50 and during combustion liberates heat to the extent of 14,000 B. t. u. per pound, the quantity of heat available for one cent will then be 112,000 B. t. u. From producer gas at four cents per thousand cubic feet and containing 150 B. t. u. per cubic foot, the heat attainable for one cent is 37,500 B. t. u. With city illuminating gas, of a calorific value of 700 B. t. u. per cubic foot and costing $1.00 per thousand cubic feet, we have 6000 B. t. u. available at a cost of one cent.

Cost of Heat from Electrical Energy. Electrical energy as distributed for lighting purposes costs in the neighborhood of ten cents per kilowatt hour. When freed from the cost of distribution and if delivered in large quantities without expensive transmission, this energy may be obtained for from one to two cents per kilowatt hour and from waterpower plants it is being sold at even lower prices, two cents per kilowatt hour being near the low limit. One kilowatt hour of electrical energy, when transformed into heat, furnishes about 3400 B. t. u., or, in other words, the heat equivalent of one kilowatt hour is represented by this figure.

Table III gives an idea of the relative cost of heat units obtained by different methods.

From Table III, it is evident that electrical heating with the lowest cost of energy obtainable is over eight times more costly than where heat is obtained from coal. The electric furnace, however, has advantages of such importance that this relative cost of heat units does not constitute a serious handicap for such a furnace. The

TABLE IV

Heat Efficiencies of Furnaces

Kind of Furnace	Efficiency
For generation of steam from coal.	50% to 60%
Blast furnace for manufacture of iron.	52% to 66%
Open hearth furnace for steel.	10% to 12%
Reverberatory furnace.	5% to 8%
Crucible steel furnace.	2% to 4%
Retort furnace for zinc.	2% to 3%
Electric furnace—for graphite.	75%
Electric furnace—for fused Al_2O_3.	75%
Electric furnace—for iron and steel.	50% to 80%

advantages of the electric furnace may be summarized chiefly as follows:

Electrical energy gives "pure, unadulterated heat" to the material which is to be treated, while many of the combustion methods involve the transmission of heat by means of the gaseous products of combustion. The efficiency of electrical heating is, therefore, greater. Table IV gives a numerical idea of the heat efficiencies of various types of industrial furnaces.

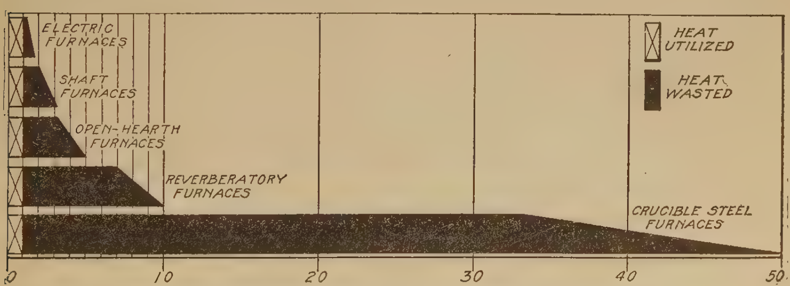


Fig. 21. Losses of Heat in Melting Metals
Copied from The Electric Furnace, by Alfred Stansfield

Fig. 21 gives a graphical representation of the heat lost and utilized in various types of furnaces for melting metals.

The chief reason for the very low efficiencies of combustion furnaces is that the waste products of combustion carry away most of the heat. In a crucible furnace this loss is so great that as much as 98 per cent of the heat energy is wasted. Radiation losses from combustion furnaces are usually greater than for electric furnaces on account of the larger size of the former.

Economy of Electric Heating. As shown in Tables III and IV, 112,000 B. t. u. are available for one cent's worth of coal, but if this heat is used for melting steel in a crucible furnace, only two per cent or 2240 B. t. u. are useful. With electric heating, however, at one-quarter cent per kilowatt hour at an efficiency of 80 per cent, 10,880 B. t. u. are actually available, and the electric heating thus becomes far cheaper even for the lower temperature metallurgical operations.

Added to this advantage of high efficiency, the electric furnace has the merit of making available high temperatures; of making possible a direct application of the heat to the material heated; of making small furnaces do the work of larger furnaces. The volumes of gaseous products which have to be handled are much less with the electric furnace, and this is also important because the gaseous products of combustion frequently interfere with the desired chemical reactions. The electric furnace can be operated with either an oxidizing or reducing atmosphere. Not the least among the advantages of the electric furnace is the more efficient use of refractory materials which is possible. The limitations upon almost all types of furnaces lie in the limitations of refractory materials which are available. In a crucible type of combustion furnace, the heat must pass through the refractory walls to get at the substance to be heated. This means that the heat to pass through this refractory material must have a higher temperature outside than inside. If, for example, iron is to be melted, having a melting temperature of 1500° C., the temperature on the outside of the crucible must be considerably higher than this. On the other hand, if electrical heating can be applied inside of the crucible, the crucible linings may be at a somewhat lower temperature than 1500°.

TYPES OF ELECTRIC FURNACES

While the transformation of electrical energy into heat energy is in itself a simple operation capable of being carried on at an efficiency of one hundred per cent, there are innumerable modifications of furnace construction and operation. Electric furnaces may be classified in two main classes, viz., the arc furnace and the resistance furnace.

Arc Furnace. The electric arc had its first great use for illumination purposes, depending for its usefulness on the fact that an arc

maintained between two carbon terminals raises these terminals to such a high temperature as to give off intense luminous radiations. Fig. 22 illustrates such an arc, maintained by the flow of direct current. The arc itself consists of a crater at each of the electrodes and a conductive gaseous medium connecting them, the location of the highest temperature being at the positive crater. This temperature is probably the highest attainable by any known means, being that of the vaporization of carbon.

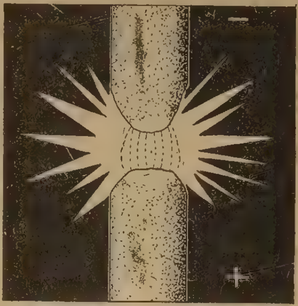


Fig. 22. The Electric Arc
Copied from The Electric Furnace, by Alfred Stansfield

Either direct or alternating current may be used for maintaining an arc and thus we have a subdivision of arc furnaces into the direct-current and the alternating-current types.

In electric furnace terminology, the term electrodes is used in a different sense from that implied in electrolytic cells, being the terminals or conducting bodies furnishing the entrance and exit of the current to and from the furnace. Carbon or graphite is almost universally employed as electrodes for the arc furnace because of

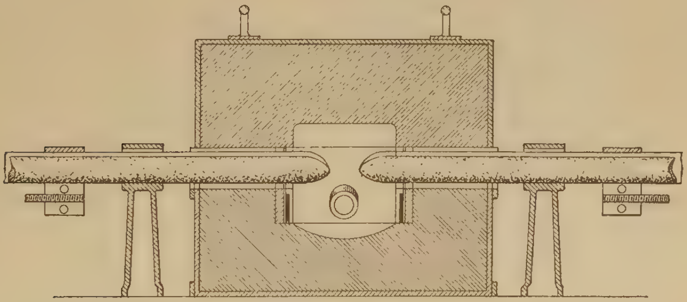


Fig. 23. Small Arc Furnace
Copied from Electric Furnace, by Wilhelm Borchers

the ability of these materials to withstand the intense heat without melting.

The arc furnace differs from the lighting arc mainly in its size and far greater power consumption and in its being enclosed within refractory walls to prevent the escape of the heat. The increased

power consumption is brought about by increased flow of current at only slightly higher voltages than those used in the arc lamp. The

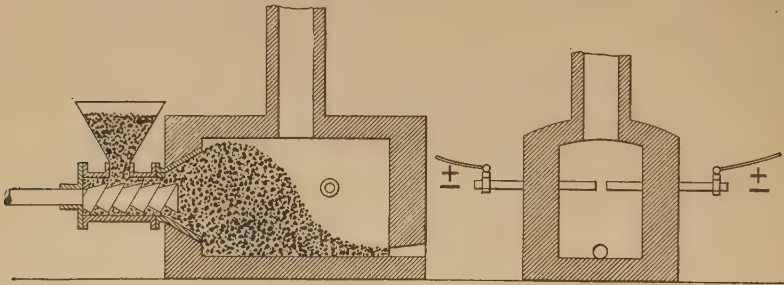


Fig. 24. Sections of an Arc-Muffle Furnace
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

pressure required to maintain a powerful arc furnace ranges usually between 50 and 100 volts, while the current consumption may be hundreds and even thousands of amperes.

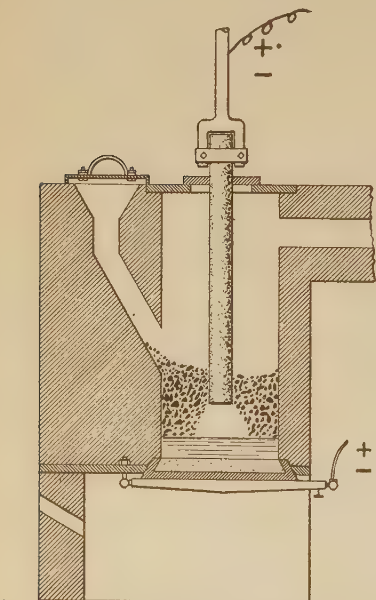


Fig. 25. Furnace with Embedded Arc
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

A small arc furnace is illustrated in Fig. 23, where the terminals of two horizontal carbon electrodes are enclosed in an iron box lined with a heavy layer of lime, magnesite, or other highly refractory material. Such a furnace has extensive use in small laboratory operations, where the heat of the arc is radiated from the craters, reflected by the walls, and conducted by the enclosed gases to the crucible or material resting on the bottom of the furnace.

Fig. 24 shows diagrammatically the same type of furnace applied to the treatment of an ore fed continually into the side of the furnace, the volatile products passing up the chimney, and the liquid metal or slag running off at the bottom.

Another modification is illustrated in Fig. 25, where the arc is actually embedded in the mass of material which is being treated.

In this case the upper electrode consists of carbon and the lower one of the liquid metal or material which is being reduced. In such form of furnace, calcium carbide may be produced, or the reduction of iron oxide may be effected.

An arc furnace in which two arcs are maintained is illustrated in Fig. 26, where *M* represents a mass of molten iron covered by a layer of slag *S*. The current entering one of the carbon electrodes passes through the arc and the slag to the iron, thence through the slag and arc to the other terminal electrode. This is a type of furnace commonly used in the electric steel industry.

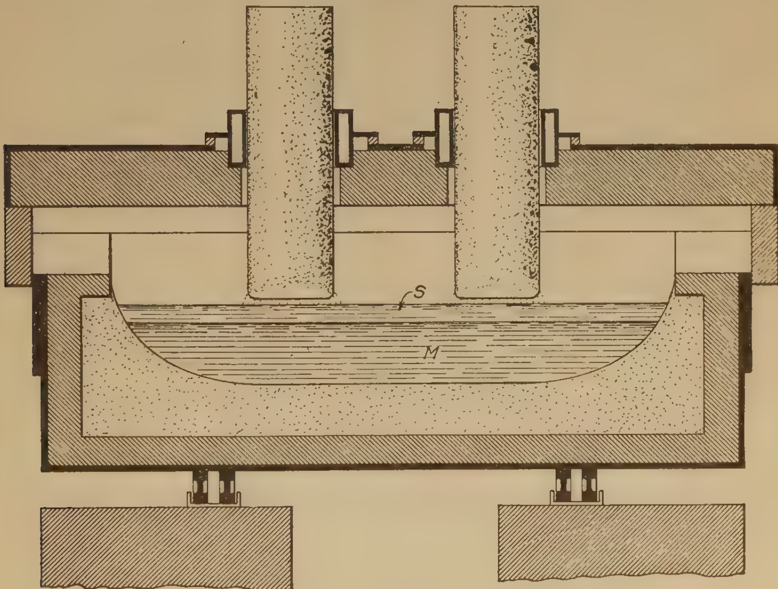


Fig. 26. Furnace with Two Arcs
Copied from The Electric Furnace, by Alfred Stansfield

Resistance Furnaces. The resistance type of furnace depends upon the fact that in passing current through a conductor heat is generated, the temperature being higher the greater the amount of current. Thus heat may be generated within the material under treatment if such material has the proper degree of conductivity. Or the heat may be conducted from the conductive mass carrying the current to a surrounding or adjacent material.

The term "resistor" is used in designating that portion of a resistance furnace which conducts the current and in which the heat

is generated. This resistor may be any one of a large variety of materials, such as granulated or crushed carbon or coke, fused

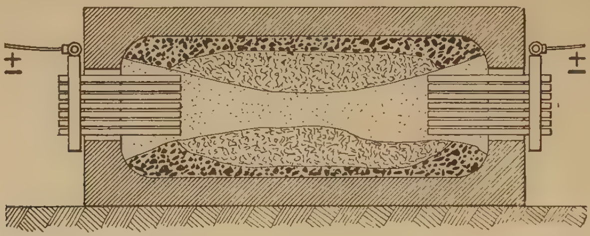


Fig. 27. Resistance Furnace for Graphite and Carborundum
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

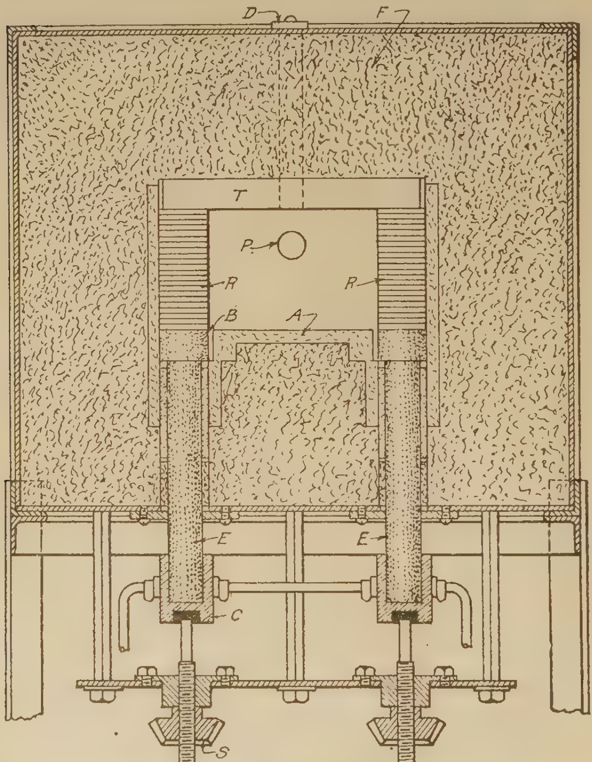


Fig. 28. Section of Muffle Furnace
R—Carbon resistor plates; T—Carbon top plates; B—Graphite bottom plates; E—Graphite electrodes; S—Regulating screws and gears; A—Special refractory cement; F—Fire brick heat insulation; P—Pyrometer hole; D—Draft hole and cover.
Courtesy of Hoskins Manufacturing Company

metals, slags, or, in fact, any material which is conductive in the liquid or solid state.

Fig. 27 shows a common type of resistance furnace, such as is used in the manufacture of graphite and carborundum. The resistor is the central column of coke, between the two terminal carbon electrodes, and surrounded by the layers of material under treatment, the whole being enclosed within the retaining walls.

Figs. 28 and 29 show a type of resistance furnace in extensive use for the heat treatment of metals and for other purposes where muffle heating is desirable on a small scale. The sectional view shows two tiers of carbon plates *R*, an upper graphite plate *T*, the carbon plates being pressed upward against this plate by graphite

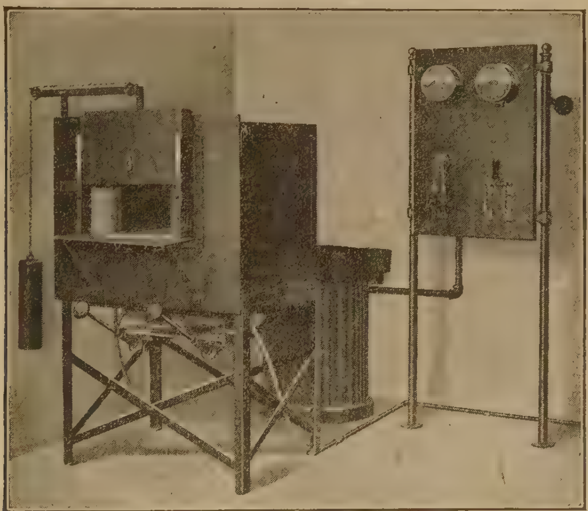


Fig. 29. Hoskins Type F C Electric Furnace
Courtesy of Hoskins Manufacturing Company

electrodes *E*. The heat is generated by the passage of the current from plate to plate, and the degree of contact is varied by the adjusting wheels at the bottom of the furnace. By this adjustment, and by varying the pressure of the current supplied to the furnace, the desired degree of heat can be attained.

COMMERCIAL PROCESSES

NON-METALLIC COMPOUNDS

Calcium Carbide. Lime and carbon mixed together and heated to a high temperature react according to the following equation:

$$CaO+3C=CaC_2+CO$$

That is, the carbon acts as a reducing agent to remove the oxygen from the lime and additional carbon unites with the lime to form calcium carbide.

The temperature required to bring about this reaction is higher than can be furnished practically by combustion furnaces. Electric heating is necessary, therefore, in the production of this compound, and this use has constituted an important electric furnace industry since 1895.

Calcium carbide is a crystalline product which has the property, upon adding water, of liberating gas according to the following reaction:

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$$

This gives C_2H_2, or acetylene, which has its most extensive application as an illuminant and it is chiefly for the production of this gas that calcium carbide is manufactured.

The process is a simple one. The raw material consists of an intimate mixture of a good grade of lime and of carbon in the form of charcoal, coke, or anthracite coal.

There are two main types of furnaces used in the treatment; in one type the calcium carbide is removed from the furnace in the form of a solid block; in the other type it is tapped from the furnace in a liquid state.

In the former type, the heating may be effected by means of an arc drawn between two carbon electrodes, the mixture being fed to the heat zone where the reaction takes place and the molten carbide flows into a mass which solidifies in the cooler portion of the furnace. The earlier methods consisted in running a box type of furnace until a certain amount of carbide had accumulated therein, when the current was interrupted and the solidified material removed and broken up for shipment. An improvement in this type consisted in forming the calcium carbide in a rotating type of furnace as illustrated in Fig. 30. The solidified core is rotated away from the arc terminals at a rate proportional to the formation of the carbide. On the opposite side of the furnace, the core is removed by breaking off pieces. This type of furnace is an improvement which insures continuous operation.

In the tapping type of furnace, an iron container lined with a refractory material with a bottom layer of carbon contains the

charge. An electrode is lowered from above, and 200 kilowatts and upward of alternating energy is supplied. The higher temperature maintains the carbide in a molten condition and at regular intervals it is tapped from the furnace into iron ladles.

In either the tapping type or the rotating solid core type, continuous operation of the furnace is possible.

The energy consumption per pound of carbide is stated to be in the neighborhood of two kilowatt hours.

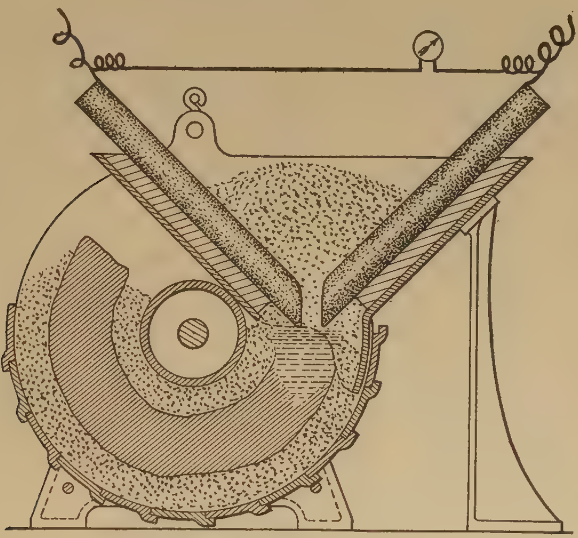


Fig. 30. Rotary Calcium Carbide Furnace
Copied from Electric Furnace, by Wilhelm Borchers

Silicon Products. Just as lime may be acted upon by carbon at high temperatures so reactions likewise take place in mixtures of carbon and silicon oxide or sand. Electric furnace temperatures are the most practical for bringing about these reactions, of which there are several possible ones depending upon the temperature and other working conditions.

One reaction may be represented by the equation

$$SiO_2 + C = SiO + CO$$

Silicon monoxide, SiO, is a brown powder. Its suggested uses are as a pigment, as a reducing agent, and as a heat insulating material. Thus far, however, it has been an unimportant technical product.

Another reaction proceeds according to the equation

$$SiO+C=Si+CO$$

That is, the silicon monoxide may be reduced by the carbon to the element silicon with the accompanying evolution of carbon monoxide. Large quantities of silicon have been produced according to this method and a material which was formerly a chemical curiosity is easily produced in large quantities. A construction of furnace which has been proposed for the production of silicon is illustrated in Fig. 31. The electric terminals of the furnace consist of two carbon electrodes introduced horizontally. Connecting these electrodes is a pile of carbon slabs acting as a resistor where the heat is generated. This resistor is surrounded by a mixture of sand and carbon and the molten silicon settles to the bottom and flows through the openings into the lower chambers. This so-called metallic silicon has a purity of about 95 per cent. It is a dense crystalline substance with a dark metallic luster. It has a melting point somewhat less than that of pure iron. Among its uses, it is employed as an addition agent to steel and it is also manufactured into crucibles and containers for resisting acids.

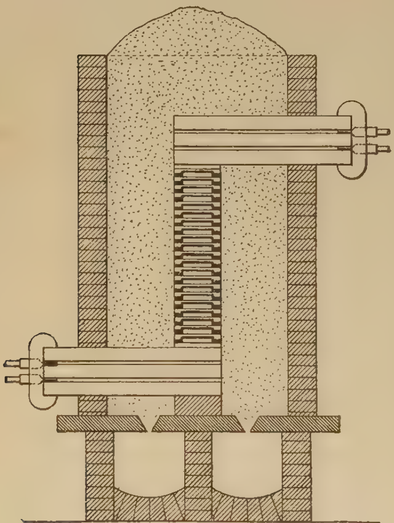


Fig. 31. Silicon Furnace
Courtesy of Electrochemical Industry

Still another reaction which may take place between sand and carbon is represented by the equation

$$SiO_2+3C=SiC+2CO$$

Carborundum. The silicon carbide, SiC, or carborundum, as it is generally known, is the most important of the products obtained from the union of the reactions between silicon and carbon. It was discovered, in 1891, by Acheson, who recognized in the hard iridescent crystal produced a material valuable as an abrasive agent.

The hardness of this material is only slightly less than that of the diamond and it is now produced in large quantities on account of this useful property.

The electric furnace is a simple type of resistor furnace in which a conductive core of carbon about three feet in diameter is placed between the end carbon electrodes which are held stationary in fire-brick walls. Packed around this carbon core is a mixture of finely

Fig. 32. Carborundum Furnace
Courtesy of The National Magazine

ground anthracite coal, or coke, with a pure silica sand, mixed approximately according to the chemical formula given above. In addition to these materials some sawdust and salt are added, the purpose of the former being to increase the porosity of the charge and allow the ready escape of the carbon monoxide gas. The presence of salt is claimed to assist in the removal of some of the metallic impurities in a volatile state.

A 2000-h.p. furnace is approximately 30 feet long and takes 6000 amperes at a terminal pressure of about 230 volts. As the core heats up, its resistance decreases so that for a constant power

consumption an increased amperage at a lower voltage must be supplied. At the end of the run the current may be 20,000 amperes at a pressure of 75 volts.

When the reaction has been completed, the furnace is allowed to cool down, the side walls are removed, and the carborundum is found as a thick shell around the inner core. Fig. 32 illustrates one of these furnaces in the process of dismantling after a run.

In the operation of carborundum furnaces, considerable quantities of graphite have been produced, especially in the hotter portions of the charge. This is explained by the fact that carborundum when

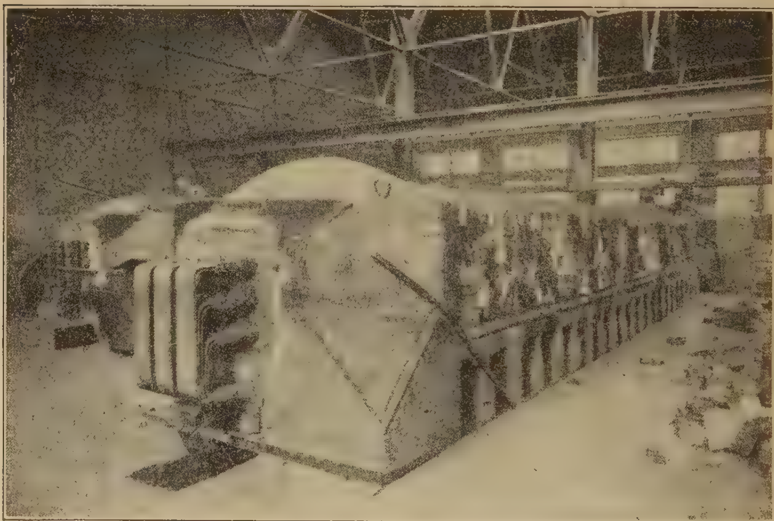


Fig. 33. Graphite Furnace
Courtesy of International Acheson Graphite Company

heated to 2200° C. decomposes, the silicon being vaporized away, leaving the carbon in the form of graphite. According to the reaction

$$SiC = Si + C$$

Graphite. One of the most spectacular, as well as important, achievements of the electric furnace is the production of artificial graphite. To Mr. Acheson belongs also the credit of its development. He found that at certain high temperatures carbon in the form of coal or coke is transformed into graphite. It has been the prevail-

ing belief that this conversion is brought about through the aid of certain oxides, such as those of silicon, aluminum, and iron. The exact way in which these oxides act is not clear, the supposition being that they act as a catalytic agent. Artificial graphite is now produced in many different grades and the number of its uses is steadily increasing.

The type of furnace for the production of graphite powder is similar to that of the carborundum, having permanent end walls with electrodes, a fire-brick bed, and removable side walls of refrac-

Fig. 34. Graphitized Electrodes
Courtesy of International Acheson Graphite Company

tory brick. When charging, a layer of carborundum sand is first placed on the bed to protect it from fusion. The charge is then filled in up to the lower portion of the electrodes. It consists usually of anthracite coal, ground to a varying size. A core of graphitized material is employed on account of its ability to conduct the current and serve as a resistor. Finally more of the charge is placed around and above the core and the furnace is covered with a layer of refractory sand to prevent oxidation.

A 1000-h.p. furnace is 30 feet long with a core diameter of 2 feet. The current increases from 3700 amperes to 9000 amperes

during heating, while the voltage decreases from the starting value of 200 down to about 80. A run may be 24 hours in length, after which the furnace is cooled sufficiently for dismantling. A graphite furnace in operation is illustrated in Fig. 33.

For the manufacture of graphite in the form of blocks or rods suitable for electrode purposes, a similar type of furnace is used. The ungraphitized articles are made from a mixture of amorphous carbon or finely powdered petroleum coke, pressed and molded with a pitch binder, after which it is calcined in a gas-fired furnace.

Fig. 35. Graphite Electrodes for Furnace Work
Courtesy of International Acheson Graphite Company

To convert these carbon bodies into graphite simply means the application of a sufficient amount of heat, to secure which the carbons are packed between the end electrodes of the graphite furnace in a bed of conductive granulated carbon or graphite. The operation is similar to that of the graphite furnace just described.

The industry is of interest to the electrochemist not only as being an electrochemical industry in itself but also as furnishing a most valuable form of carbon for electrolytic and electric furnace work. Fig. 34 illustrates various forms of graphite electrodes while

Fig. 35 illustrates large graphitized carbon cylinders arranged to be fitted together for use in electric furnaces.

Alundum. Alundum is another electric furnace product which has a commercial value as an abrasive, also as a highly refractory material. Alundum is the trade name given to fused aluminum oxide. It is made by first purifying bauxite and then fusing it in an electric arc furnace. The furnace consists of a circular hearth of carbon blocks with a removable wall of sheet iron, water-jacketed throughout. Two carbon electrodes introduced from above convey the alternating current to and from the furnace. When a sufficient

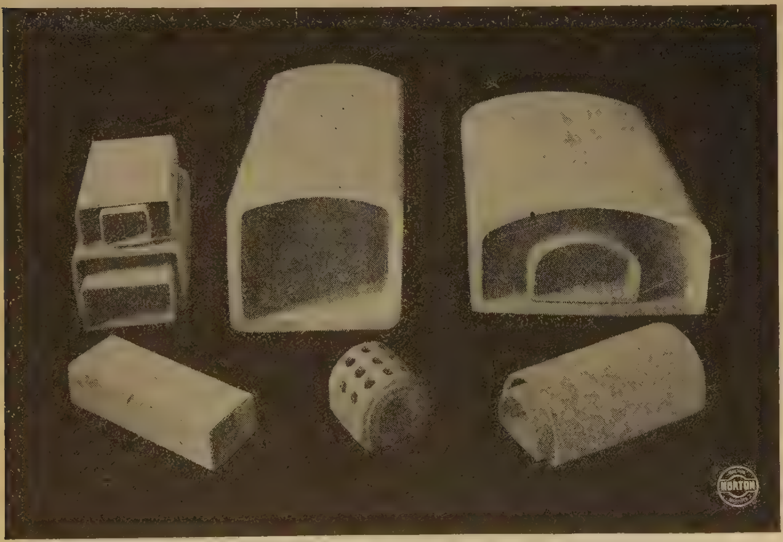


Fig. 36. Alundum Muffles
Courtesy of The Norton Company

quantity of the fused material has formed, the solidified material is removed and broken up, crushed, and graded.

From the finely crushed material, grinding wheels are formed, and it is also used in the construction of crucibles and muffles such as illustrated in Fig. 36.

Carbon Bisulphide. One of the big electric furnace achievements is its recently attained monopoly in the production of carbon bisulphide. This is a liquid of the chemical composition of CS_2. The Taylor furnace, by which practically all of the supply of material used in this country is manufactured, is of the resistor type, illus-

trated in Fig. 37. It is a fire-brick structure, enclosed in a strong iron shell. The resistor consists of pieces of coke or of broken electrode carbons fed into and occupying the space at the bottom of the furnace, and terminal electrodes of carbon supplying the current to this resistor material. The form of carbon used for the resistor does not react readily with sulphur, but the contrary is true of the charcoal which is fed in at the top of the furnace and occupies most of the space in the upright cylinder. The sulphur is introduced into the hearth of the furnace below the electrodes, where it is vaporized and passes upward through the charcoal where the reaction takes place. The carbon bisulphide vapors leave the furnace at a comparatively low temperature.

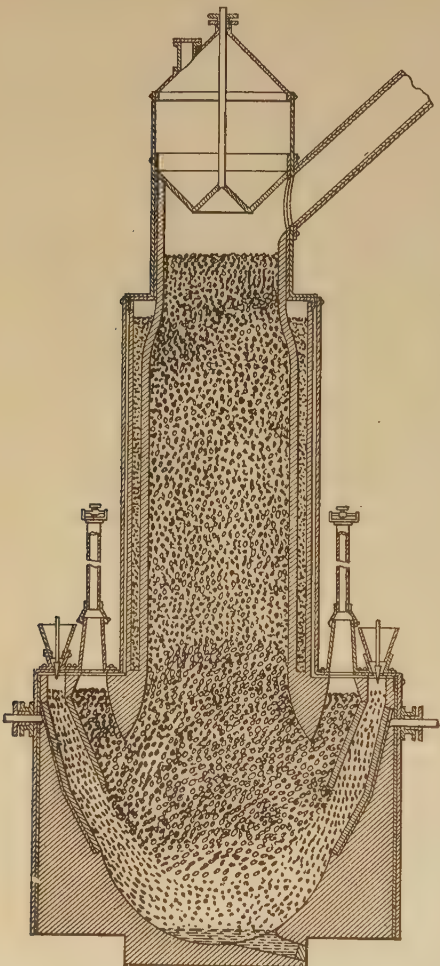


Fig. 37. Carbon Bisulphide Furnace
Copied from Production of Carbon Bisulphide, by Taylor

ELECTRIC FURNACES IN THE STEEL INDUSTRY

After years of experimental and exploitation work, the electric furnace has reached a position of commercial importance in the iron and steel industry. While at present a comparatively small tonnage of steel is influenced by electric furnace development, there is a general prediction that the electric furnace is going to become of great importance.

The different ways in which the electric furnace may be used in this industry may be classified as follows:

(1) The direct reduction of iron from its ores, producing either a pig iron or finished steel.
(2) Replacing or supplementing the existing types of metallurgical furnaces for the manufacture of steel from pig iron.
(3) The replacement of the crucible process by the electric furnace.
(4) For the heating of billets and bars, for the purpose of heat treatment or for rolling and drawing purposes.

Direct Reduction of Iron from Its Ores. For this purpose the electric furnace must replace the ordinary blast furnace in which the iron ore is reduced by being mixed with coke or other form of carbon, the heat for reduction being supplied by the combustion of the fuel. This type of furnace has a high thermal efficiency, being above 50 per cent, and from the standpoint of cost of energy, the electric furnace has little opportunity for competing. The electric furnace, however, supplies heat by the transformation of electrical energy, while the heat from the blast furnace must be obtained from the combustion of the carbon in the furnace charge. Therefore, with the electric method a material saving can be made in the amount of coke or other form of carbon used, and this method is therefore advantageous where fuel is scarce and waterpower plentiful. Furthermore, a higher temperature can be obtained by the electrical method of heating so that certain refractory ores can be reduced in the electric furnace which would clog up the ordinary blast furnace.

For the successful direct smelting of iron ores there is required a very cheap source of electric power in a location where there is a market for the product, also a convenient source of iron ore, and where a saving in the amount of carbon used is of importance; in other words, where the price of coke or charcoal is high. These conditions are found in only a few places, such as along the Pacific Coast, where extensive experiments along this line have been carried out. In the industrial centers, however, the direct reduction of iron ores does not seem to be practicable by the electrical method.

Manufacture of Steel from Pig Iron. Steel is commonly made from pig iron by taking the molten iron as it comes from the blast furnace and putting it through a refining operation, in the Bessemer or open hearth, or other similar refining process. If the refining is not done in conjunction with the smelting operation, the pig iron is

shipped to the place where the refining plant is installed, and in this case the pig iron must first be melted up.

It is evident that there are various ways in which the electric furnace may be employed, either to replace or to supplement the ordinary refining operations. Instead of running the molten pig iron into the Bessemer converter, the hot metal may be run into an electric furnace and the refining operation carried on by the addition of the electrical heat which may raise the charge to any desired temperature. On the other hand, the electric furnace may be used only as a finishing step after a certain amount of refining has been done by the ordinary process.

Temperature is an important factor in the refining operation, and under the higher temperatures available in the electric furnace, the refining may be carried out more quickly and to a higher degree than is possible by the fuel methods of heating. For such purpose the electric heating has a high thermal efficiency as against the much lower thermal efficiency of the gas- or fuel-heated furnace; and in taking the molten material from the blast furnace or melting furnace, heated by fuels, the electric furnace is called upon only to do the high temperature, or critical, part of the work. It is claimed that by its use a specially high quality of steel may be secured and that the uniformity of the product is much greater than is otherwise attainable.

Manufacture cf Crucible Steel. In the manufacture of high grade tool steel, the electric furnace seems to have its most marked field of usefulness.

The crucible process, as ordinarily carried out, consists in melting up in graphite or plumbago crucibles a commercial grade of pure iron and adding the purifying and alloying agents which are required. The crucibles, costing about $2.50 each, will hold about 100 pounds of metal and can be used six or seven times. These crucibles are heated by the products of combustion and the thermal efficiency is very low, being in the neighborhood of two per cent. The electric furnace with its 80 per cent efficiency is, therefore, able to compete profitably, and the high cost of crucible maintenance gives the electric furnace another opportunity to win out in the struggle for supremacy.

Arc Type of Furnace for Iron and Steel. The various forms of the arc type of furnace are playing the more important part in the

electrometallurgy of iron. As illustrative of the leading forms of arc furnace, reference may be made to Fig. 38, showing the Stassano, the Heroult, and the Girod methods of operation.

Stassano Furnace. This furnace in practice assumes several forms. It consists of a thick walled, rectangular chamber with a slightly arched roof. The electrodes are introduced into the side of the furnace and the raw material charged in at the ends. Tapping holes are provided for the slag and the finished steel. Another modification takes a circular form in which the entire furnace is

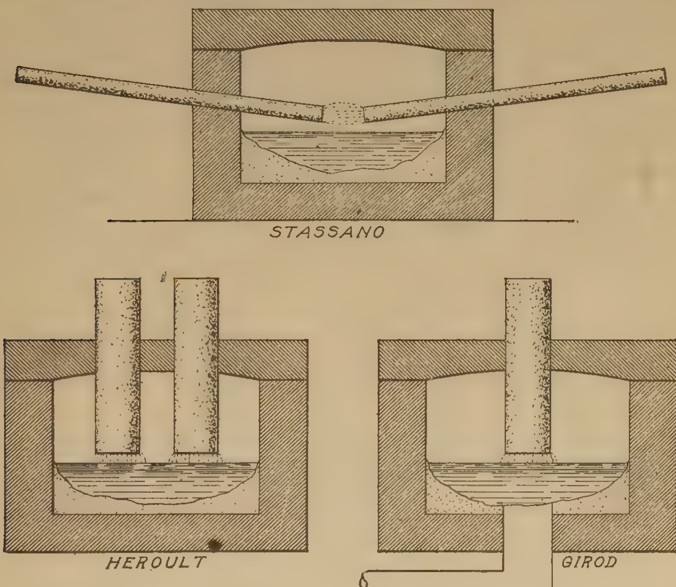


Fig. 38. Sections of Three Representative Types of Steel Furnaces

slightly inclined and rotated slowly about its axis so as to give some agitation to the furnace contents. The fixed type of furnace has been designed up to a capacity of 750 kw., while the rotating furnace has a capacity of about 200 kw. This furnace operates at a pressure of about 150 volts, somewhat higher than is usual with arc furnaces on account of the long arc which is employed.

Heroult Furnace. This furnace, which appears to be most widely used in this country, is of a simple construction consisting of a shallow hearth lined with refractory material and roofed over with silica brick. The contents are discharged by tilting the entire furnace, together with the electrode supports. Two electrodes enter

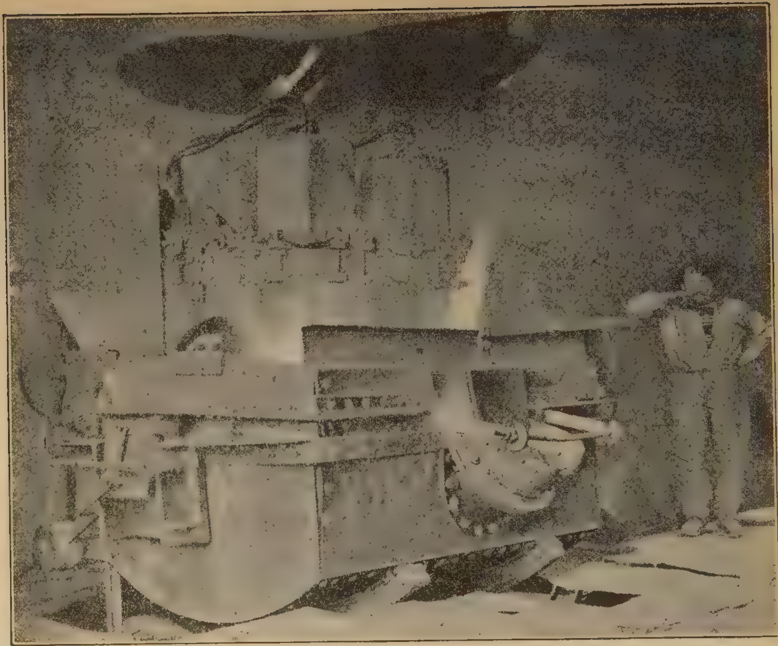


Fig. 39. Heroult Furnace in Operation
Courtesy of Société Electro-Métallurgique Française

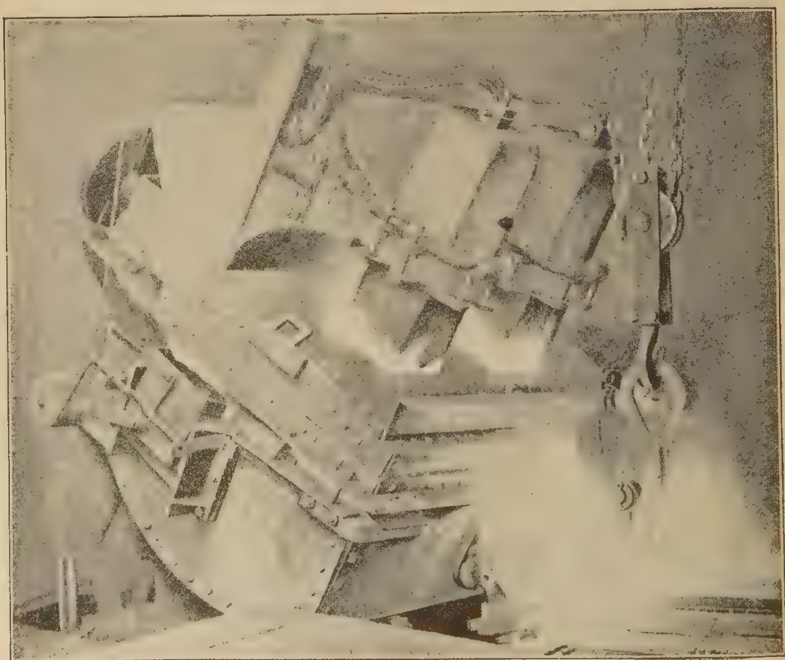


Fig. 40. Heroult Furnace Discharging Molten Steel
Courtesy of Société Electro-Métallurgique Française

vertically through openings in the roof and project down to within one or two inches of the surface of the bath. They may be water cooled at the points where they pass through the roof as well as at

Fig. 41. Steel Furnace About to Pour Its Charge
Courtesy of The Iron Age

the cable connections. Furnaces of a capacity of from 15 to 20 tons have been used and operated at pressures of from 45 volts to 100 volts, depending upon the energy input. A 15-ton furnace requires

up to 2000 kw. Fig. 39 illustrates the Heroult type of furnace in operation, while Fig. 40 shows the tilting operation for discharging the finished product.

Girod Furnace. This furnace differs from the Heroult in that the current enters through the electrode in the roof of the furnace,

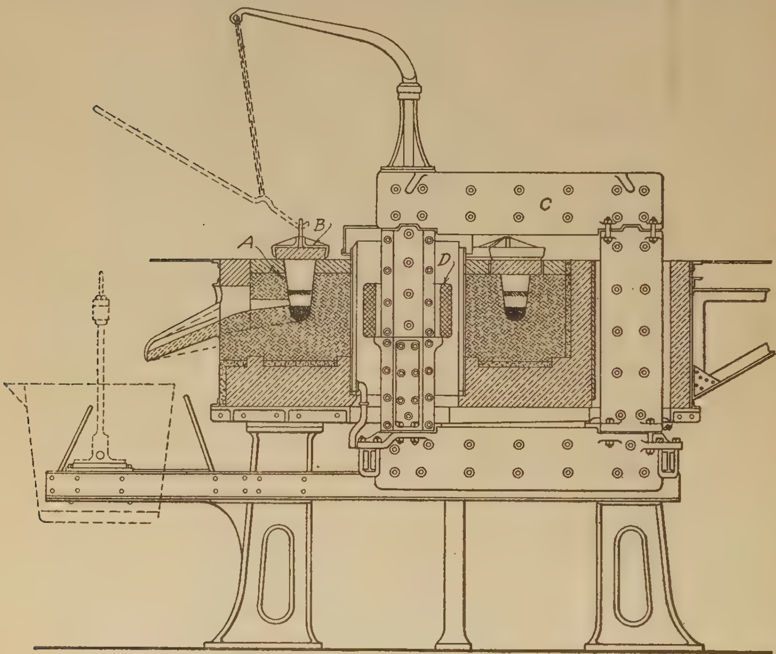


Fig. 42. Cross Section of an Induction Furnace
Courtesy of American Electric Furnace Company

Fig. 41, arcs across to the slag, then through the steel bath, finally leaving by one or more steel electrodes embedded in the refractory hearth material. Thus instead of having two arcs in series there is only one. The voltage of this furnace is, therefore, approximately half that of the Heroult type and with furnaces of equal load the current is necessarily twice as great. These furnaces have been built up to capacities of 15 tons. The voltage varies between 55 and 75 volts and a 300-kw. furnace will take from 5000 to 5500 amperes and a 1200-kw. unit will take 20,000 amperes.

Induction Steel Furnaces. An important type of steel furnace is what is known as the induction type, whereby the use of electrodes is entirely avoided, as is also the contamination of the steel by pieces

of carbon breaking off from the electrodes. The absence of carbon electrodes is made possible by causing the molten metal, in a continuous circuit, to carry the energy which is applied to it by magnetic induction. In other words, an induction furnace is a step-down

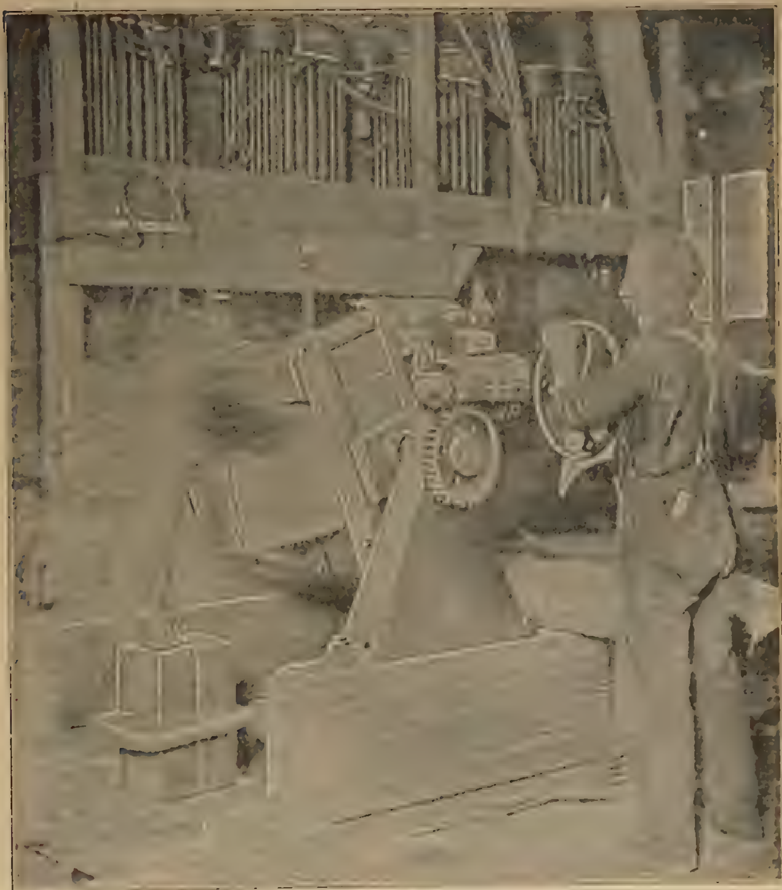


Fig. 43. Induction Furnace in Operation
Courtesy of American Electric Furnace Company

transformer with a short circuited secondary consisting of a single turn of the molten metal. It is obvious that the molten metal must be confined in a channel surrounding the core of the transformer, which core is also wound with a winding of a suitable number of turns to correspond with the alternating voltage which is applied.

Fig. 42 shows the cross section of an induction furnace, C representing the iron core, or transformer, D the winding placed thereon, A the molten metal constituting the single turn secondary embedded in a refractory channel, and B the refractory cover for this channel.

To get such a furnace in operation, it is necessary that there be a continual metal mass, which is afforded by pouring molten metal into the furnace. When a pour is made from the furnace, care is taken to retain some of the metal to act as a starter for the next run.

As counterbalancing the obvious advantages, this furnace has losses and disadvantages which have restricted its general use. It is subject to magnetic and electrical losses due to hysteresis in the iron core, heat losses in the primary circuit, and magnetic leakage. Furthermore, there is a large heat radiating surface by reason of the long channel which must be employed for a given quantity of metal. Fig. 43 shows the operation of a small induction type of furnace.

ELECTRICAL DISCHARGE IN GASES

Thus far consideration has been given to the use of currents passing through solid or liquid conducting materials where comparatively low voltages are required; also to a certain vapor type of conduction in the low voltage electric arc.

Characteristics of Discharge. A new and rapidly developing field of applied electrochemistry utilizes phenomena attendant upon the application of high voltages to gaseous media. Fig. 44 conveys diagrammatically an idea of the relation of current and voltage when an increasing difference of potential is applied to two similar electrodes separated by air or other gas. As the voltage is increased from zero, there is little flow of current or, in other words, the electrodes are practically insulated. By sufficiently sensitive instruments a slight flow of current may be detected, as indicated by the portion of the curve marked "non-luminous discharge". This produces no physical or chemical effects and is unimportant from the practical standpoint. Upon reaching a certain voltage, however, there is a discontinuity of the curve, the current increases, and the discharge between the electrodes becomes luminous. The appearance and exact nature of this luminous discharge vary, being dependent upon whether direct or alternating currents are flowing,

the shape of the electrodes, and various other factors. It is designated as a glow or brush discharge. The intensity becomes greater as the voltage increases, and when air is a medium, the oxygen is conveyed into ozone.

The current for the brush discharge becomes a maximum at a certain voltage, indicated by the highest point on the curve, after which there is a more rapid increase in current, and a marked lowering of the voltage is necessary in order to keep the discharge under control. The discharge then assumes the form of the high tension arc. The sparking is very pronounced and the discharge is active

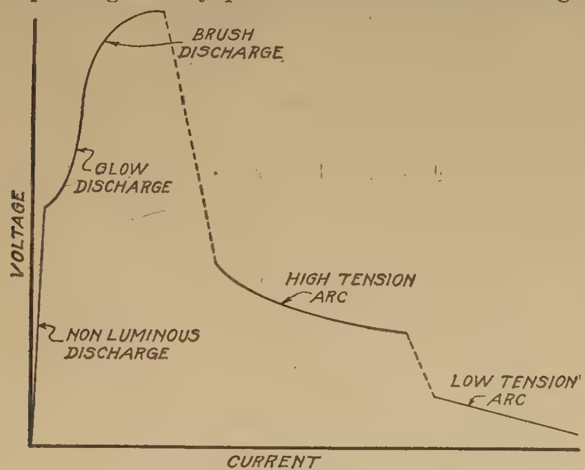


Fig. 44. Curve Showing Relation of Current and Voltage with Increasing Potential at the Terminals

in producing nitric oxide from the air. The fact that the voltage falls is due to the increased conductivity of the gaseous medium caused, in turn, by the higher temperature produced by the increased current. This form of arc has important technical uses which will be illustrated later.

If the current of the high tension arc is allowed to increase, a point is reached where the low tension arc is produced. This is a form of arc which has been previously considered in connection with arc lights and the arc furnace.

PRODUCTION OF OZONE

Ozone is a polymerized form of oxygen. It has a molecular formula of O_3 instead of O_2, the symbol for oxygen. In other words,

a molecule has three atoms of oxygen instead of two. It has a powerful oxidizing property which makes it highly useful for bleaching, disinfecting, oxidizing oils, etc. Its most extensive use is for water purification.

Ozone from Oxygen. Oxygen can be converted into ozone by heating to a very high temperature and then suddenly cooling, but only small yields are produced by this method. The use of the silent electric discharge at room temperatures avoids this difficulty.

Siemens-Halske Ozonizer. A great number of forms of technical ozonizers have been proposed. The Siemens-Halske apparatus, indicated in Fig. 45, is an important type of commercial apparatus

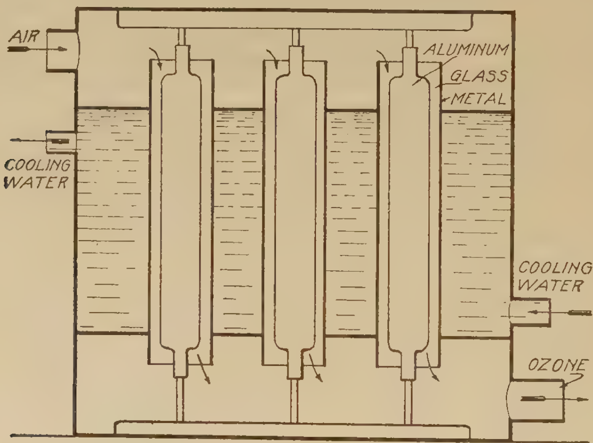


Fig. 45. Section of Siemens and Halske Ozonizer

used in water-purification plants. It consists of an iron container provided with glass windows. Passing upward through the container are a number of vertical glass cylinders coated outside with a metal which serves as one electrode. In the center of these tubes are placed the other electrodes consisting of cylinders of aluminum foil. Water is run through the container outside of the tubes to keep the apparatus cool and keep up the efficiency. The air is previously dried by means of calcium chloride or some other suitable drying agent and passes along the annular spaces between the electrodes. The metal outside of the tubes is connected to one terminal of a high alternating pressure and the inner electrodes are

connected to the other terminal. The iron container is connected to earth, thus preventing a risk to the operator.

A pressure of from 4000 to 7000 volts has been used on this type of ozonizer, and plants for water purification have been operated in Paris and St. Petersburg.

By placing the apparatus in a darkened room it is possible to tell from the luminous appearance whether it is working properly. It is claimed that with an expenditure of 57 kilowatt hours, a million gallons of water may be sterilized by this means. The method of sterilization consists in compressing the ozonized air and forcing it up through towers down which the water is passing.

FIXATION OF NITROGEN*

The most important use of the high tension electric arc is in the so-called fixation of atmospheric nitrogen.

Nitrogen for Fertilizers. Nitrogen is the most important element which gives value to our principal fertilizers. The increasing demand for such fertilizers and the approaching exhaustion of the great deposits of sodium nitrate and other natural nitrogen compounds make the problem of the future supply of great importance. The atmosphere contains a free and inexhaustible supply of this element, but in this form it is not directly useful because it is not "fixed", that is, in combination with other elements which appear to be essential for its usefulness in the growing of crops.

It has long been known that where a high tension discharge takes place, there is a partial union of the oxygen and nitrogen of the air to form the chemical compound NO.

Following the design and operation of a great many types of apparatus, it was found advisable to avoid short thick arcs and to employ long thin stable arcs which would come in contact with a large quantity of air. Units of large capacity in consuming much energy have been worked out.

Birkeland-Eyde Process. An electric furnace devised by Birkeland and Eyde has achieved a notable success in the fixation of nitrogen of the air. In this furnace a large surface of contact of air and arc is attained. The principle is illustrated in Fig. 46. Two

* An exhaustive treatise on the utilization of atmospheric nitrogen is published by the Department of Commerce and Labor, under the authorship of Thomas H. Norton.

water-cooled copper electrodes are brought within a distance of one inch or less and are connected through an inductive resistance to a

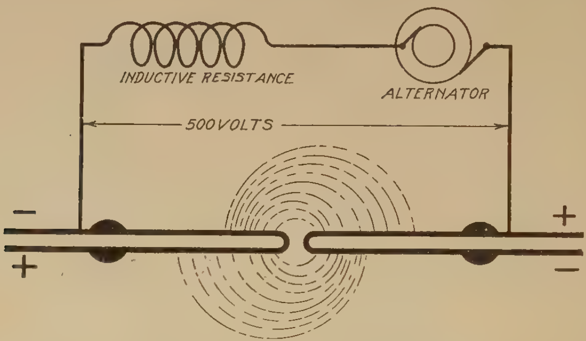


Fig. 46. Diagram of the Electric Circuit in the Birkeland-Eyde Electric Furnace

source of alternating pressure of 5000 volts. The high tension arc which is first produced quickly breaks down to a low voltage arc carrying a heavy current. This low voltage arc is avoided by an ingenious method of placing the poles of a powerful electromagnet at either side of the arc, Fig. 47. It is well known that a conductor located in a magnetic field and carrying a current tends to move out of that field. The electric arc follows this law and tends to move upward or downward, depending upon the direction of the current. In moving away from the straight line connecting the two ends of the electrodes, it becomes lengthened and this lengthening tends to maintain the arc as a high tension arc and avoids the low tension form. In moving away and lengthening, the resistance increases, the current falls off, but the voltage increases because of the

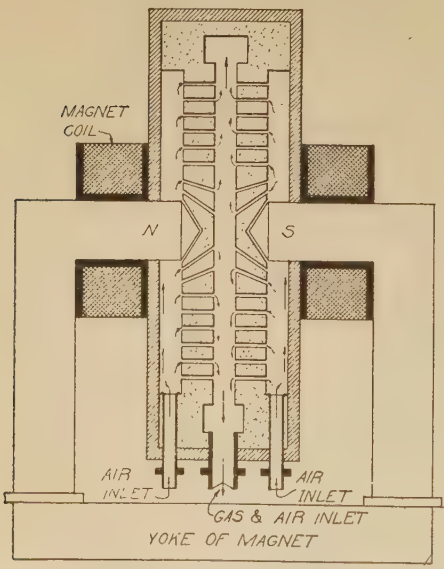


Fig. 47. Birkeland-Eyde Furnace

lower voltage drop through the inductive resistance. The arc is finally drawn to such a length that it breaks and a new arc is then established and goes through the same process. By using an alternating current, the arc formed by one-half of the alternating-current wave travels upward from the electrode and on the reversal of the current an arc is formed which travels downward, and these arcs are formed at the rate of fifty per second, in accordance with the frequency of the current used. On account of this high frequency it is impossible to detect each separate arc and in looking into the furnace what is seen is apparently a large disk sheet of light. The air is introduced

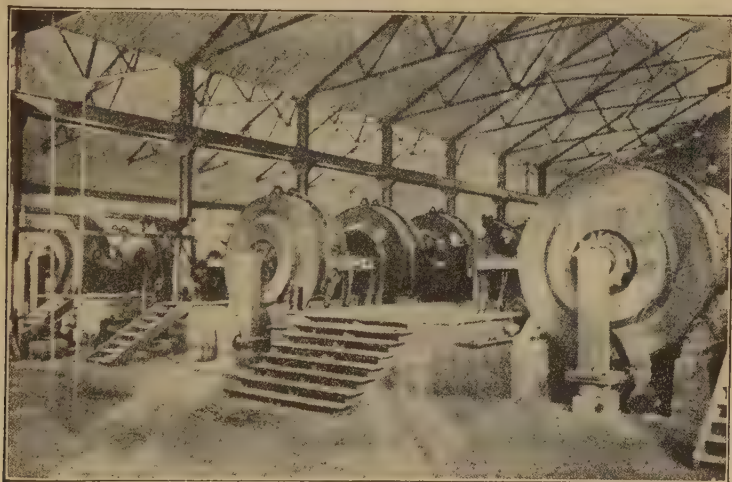


Fig. 48. Birkeland-Eyde Furnaces at Notodden

so that it travels parallel with this disk and is, therefore, fully exposed to the action of the discharge.

It is estimated that the temperature of the disk is about 2300° C. The furnace is of steel, lined with fire-bricks which are perforated by holes through which the air enters.

Units of 750 kw. have been employed, such units requiring a pressure of 5000 volts. The full sized units in operation are illustrated in Fig. 48.

ELECTRICAL FUME PRECIPITATION

Another important application of high tension currents is in the removal of suspended particles of solid or liquid materials from

gases. It has long been known that the fine particles constituting fog, dust, and fume, may be quickly settled by passing between two electrodes at which a high pressure is maintained. There is an agglomerating effect on the suspended particles which causes them to produce larger bodies which settle by gravity. When direct pressures are employed, there is an actual attraction between the electrodes and the agglomerated particles, which increases the rate of settling or collection.

Recovery of Valuable Products of Combustion. This phenomenon has a commercial application in the settling of valuable materials which are carried in furnace gases, not only to render these gases less objectionable to the surrounding territory, but also to recover valuable materials which would otherwise be lost. It also looks promising in connection with the smoke problem. There are likewise innumerable instances in industrial work where the separation of solid and liquid particles from the air can be advantageously effected by this method.

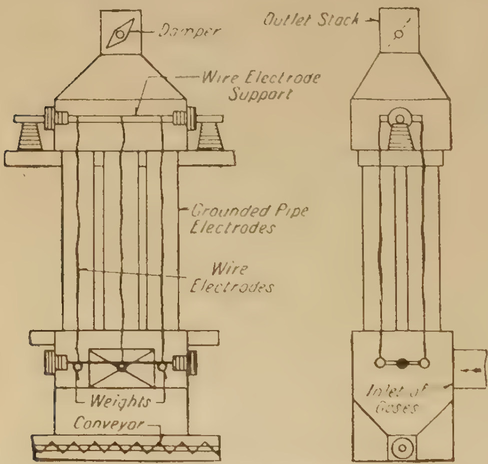


Fig. 49. Diagram of Electrical Precipitation Pipe Treater

Cottrell Process. The commercial practicability of this action of high tension currents has been demonstrated recently in the work of Dr. Cottrell and the United States Bureau of Mines. The accompanying schematic diagram, Fig. 49, illustrates a typical pipe treater. In general it consists of two large horizontal flues connected together by a number of small vertical pipes. Gases enter through one flue, pass through the vertical pipes and are discharged through the other flue to a stack, exhaust fan, or other draft producer. The gas is then exhausted into the atmosphere. Some treaters are operated with an up draft, some with a down draft, according to the particular local conditions to be met.

Some treaters employ rectangular passages instead of pipes to connect the two flues. These are generally referred to as plate or box type treaters. The principle of operation for all these types of treaters is the same.

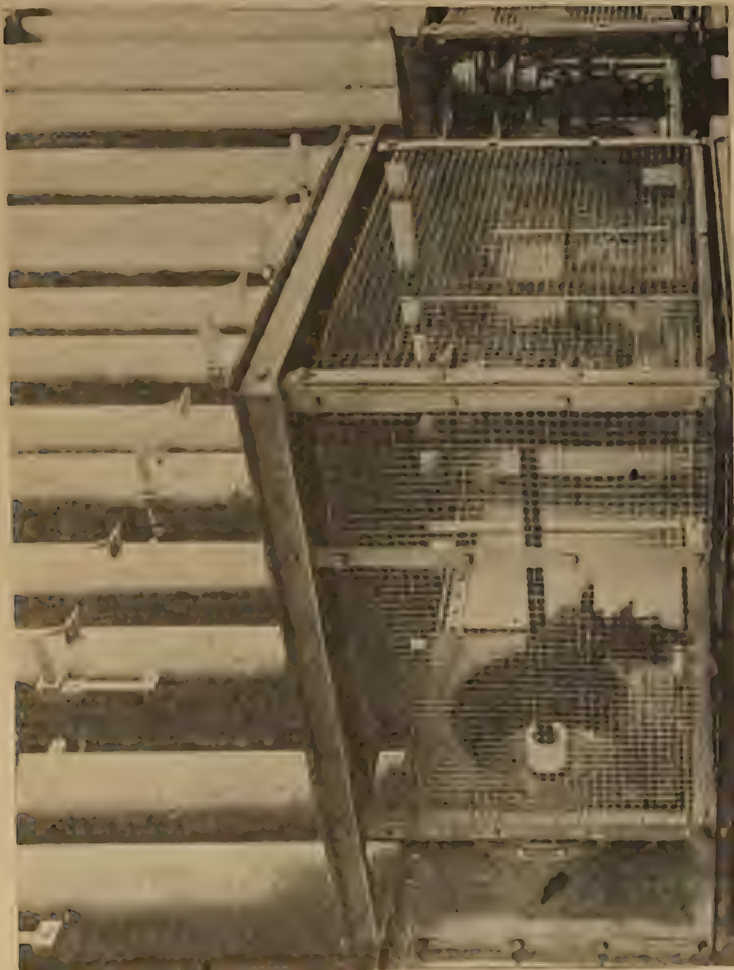


Fig. 50. [illegible] Tubes, showing Provisions for Hanging Tubes and Insulated Supports for Electrodes
Courtesy of International Smelting Company, Miami, Arizona

The actual precipitation of the dust or fume occurs in the vertical pipes referred to above. Carefully centered in each, is suspended a small wire or a small chain. These constitute the negative electrode of the treater system. The inside surface of the pipes constitute the positive electrode. Each wire or chain is

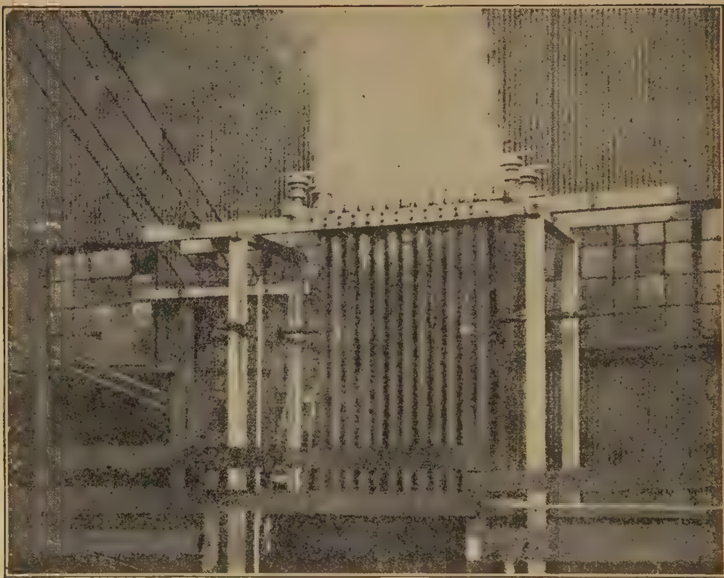


Fig. 51. Experimental Tubular Treater Before Application of Current. Fumes in the Center Above Apparatus

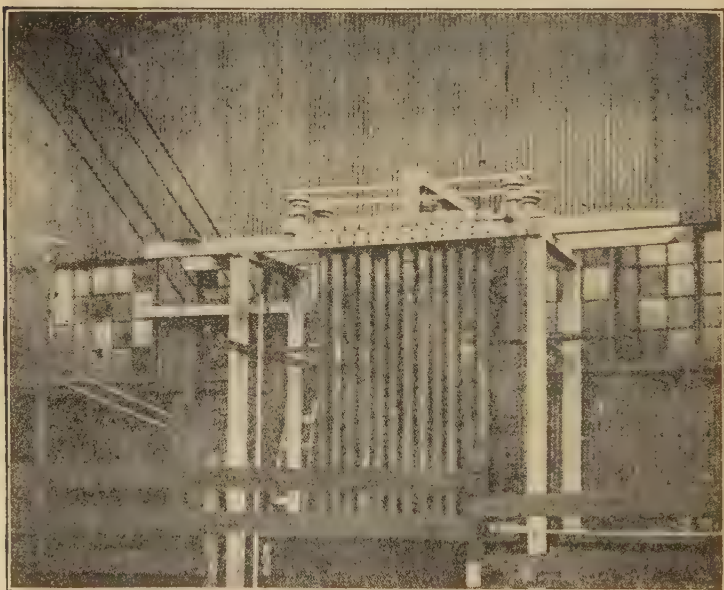


Fig. 52. Tubular Treater After Current Has Been Turned On, Showing Dissipation of Fumes

carefully insulated from its pipe and from the ground, and is charged to a high potential usually at from 25,000 to 65,000 volts direct current. The tubes themselves are grounded. Thus within each pipe is created an intense electrostatic field. The gases passing through this field become ionized, and the ions travel with high velocity in a direction at right angles to the electrodes causing the field. These highly charged ions are continually colliding with the suspended solid and liquid particles in the gas, and the ions impart a charge of like potential to such particles, which in turn begin to travel toward the electrode of opposite polarity. Since the negative suspended electrode is of much smaller area than the electrode formed by the inside surface of the pipe there is much greater electrostatic stresses per unit of area in the neighborhood of the wire, and as a result far greater ionization about the wire. Thus the gas receives a static charge of the same polarity as the wire, and the solid or liquid particles in the gas receive charges of this same polarity which cause them to be projected against the inner surface of the pipes, where they tend to stick and accumulate until the electric power is turned off, after which the accumulation of dust is usually collected from the pipes by loosening it by rapping the sides of the pipes and collecting the dust in hoppers at the bottom.

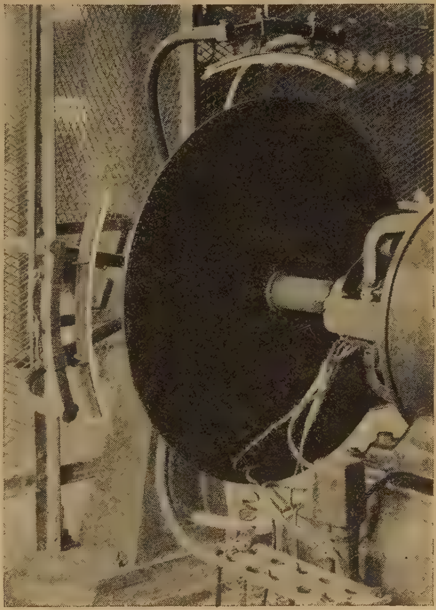


Fig. 53. Mechanical Rectifier Mounted on Extension of Westinghouse Motor-Generator Shaft, Showing Contact Shoe and Contact Arc

The treater tubes are usually arranged in a series of units illustrated in Fig. 50. Each unit or section is independent of the rest and is supplied with dampers and electrical disconnecting switches, so that it can be shut down for cleaning or repairs with-

out interfering with the operation of the other sections. The effect of turning on the current to an experimental apparatus used in connection with a copper converter is shown in Figs. 51 and 52.

Direct current at 100,000 volts is usually obtained from a low-voltage alternating current by means of a specially designed step-up transformer provided with tapped windings for varying the voltage. The high-tension alternating current is then changed into a uni-directional or intermittent current by a mechanically driven rectifier which operates on the same principle as the commutator of a direct current generator. The disc-type rectifier, shown in Fig. 53, is generally used, except where heavy currents are rectified; then the arm-type is used.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

1. What is the standard unit of luminous intensity?

2. What are the essential parts of a photometer?

3. Describe the gas-filled type of incandescent lamp.

4. Explain the principle of the electric arc.

5. What is meant by the term *efficiency of an incandescent lamp?*

6. What three systems of lighting are used for interior lighting?

7. Give a short description of the preparation of the filament in incandescent lamps.

8. Explain the principle of the flaming arc lamp.

9. What is specular reflection?

10. What principles should be observed when designing a school lighting system?

11. Name some of the advantages of exterior lighting of industrial properties.

12. What are two advantages of opal glass as a reflecting material?

13. Define *glare*. What are some of the principal factors of glare?

14. What are the two electric illuminants satisfactory for interior lighting?

15. How does the finish of walls and ceilings of an office affect the efficiency of a lighting installation?

16. Calculate the approximate illumination at the center of a plane 3 feet above the floor in a room 18 feet square and 12 feet high, the room to be lighted by four 16 candle-power lamps placed one at the center of each side wall 10 feet above the floor; the coefficient of reflection of the wall to be taken as 60 per cent.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING OF TRAINS

---

1. Name some of the practical reasons for lighting trains electrically.

2. What are the essential parts of a typical axle-light equipment? Of a head-end system?

3. What are the five general control methods of generator regulation?

4. What is a *pole-changer?* With what types of equipment is it necessary?

5. What is a stop-charge coil? Under what conditions does it operate?

6. What voltage is generally used for car-lighting lamps?

7. What is an ampere-hour meter? What does it indicate, and what does it do?

8. What is the best indication of the state of charge in a storage battery? When inspecting, what other points must be determined?

9. What is the function of the automatic switch in the Gould Simplex System? Under what conditions does it operate?

10. Above what train speed does the Kennedy regulator maintain a constant voltage? Does the regulator, at any speed, permit current to flow from the battery to the generator?

11. Name some of the causes of failure of the Type F safety regulator.

12. What are two of the differences between the Electric Storage Battery Constant-Voltage Axle-Lighting System and the Stone-Franklin System?

13. Describe briefly the Locomotive Head-End Lighting System.

14. Name some of the mechanical sources of trouble with car-lighting systems.

15. What are some of the common causes of sparking? Of overheating?

REVIEW QUESTIONS

ON THE SUBJECT OF

APPLIED ELECTROCHEMISTRY

---

1. How may chemical reactions be classified?

2. Which are the most important applications of electric energy to materials?

3. Into what classes are electric conductors divided?

4. Into what divisions may liquid conductors be divided?

5. Discuss the conductivity of water.

6. What is an electrochemical cell?

7. What is an anode; a cathode?

8. Define cathions and anions.

9. State Faraday's laws pertaining to electrolysis.

10. Assume that in the corrosion of underground water pipes by electrolysis there is an average flow of current of .001 ampere per square foot of surface. How much iron will be removed on each square foot in a year's time?

11. Define electrochemical equivalent.

12. What method is commonly used to provide an insoluble metal anode?

13. Describe a simple experimental cell for refining copper.

14. What is electroplating?

15. Describe the arrangement of an electroplating cell.

16. At what voltage do electroplating dynamos run?

17. What are the important factors determining the quality of an electro deposit?

18. In polishing nickel plating, it frequently happens that the nickel peels off. Where may the causes of this be found and what remedial measures applied?

19. Give the chemical formula according to which the production of sodium hypochlorite takes place.

20. Compare the respective advantages of the diaphragm and mercury type of cells for the production of chlorine and caustic soda.

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